A Survey of Headwater Lakes in Insular Newfoundland, With Special Reference to Acid Precipitation

D.A. Scruton

Fisheries Research Branch
Department of Fisheries and Oceans
P.O. Box 5667
St. John's, Newfoundland A1C 5X1

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D. A. Scruton

Fisheries Research Branch
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St. John's, Newfoundland A1C 5X1

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ABSTRACT

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One hundred and nine (109) small headwater lakes on the island of Newfoundland, ranging in size from 21 to 2519 ha, were surveyed from August 16 to October 18, 1981. Lakes were sampled for morphometry, water chemistry, zoo- and nanno-plankton, sediments, benthos, and fish. Water chemistry was highly variable between lakes with bedrock geology, input of marine aerosols and atmospheric deposition the dominant features controlling variability in chemical parameters. Lake pH varied from 4.90 to 8.39 with ten (10) lakes having a pH of less than 5.50. Ninety-three (93) lakes had alkalinities of less than 200 μeq L^{-1}, indicating moderate to high sensitivity to acidification. Excess sulphate values ranged from 5.7 to 91.4 μeq L^{-1} (mean of 34.5) and these levels are less than those reported for lakes experiencing moderate to high atmospheric loadings. Study lakes were highly coloured (mean of 48 TCU) which correlates to high natural acidity and also complicates assessment of anthropogenic acidification. Sensitive lakes demonstrated a sulphate dominance over bicarbonate and an alkalinity deficiency relative to major cations. Models developed by Henriksen suggest that acidification in five (5) lakes can be related to mineral acids (sulphate deposition) while in twelve (12) lakes natural organic acidity is a major contributing factor. Aluminum and manganese levels in lake water varied from 0 to 430 mgL^{-1} (mean of 112) and from 0 to 52 mgL^{-1} (mean of 13) respectively, reflecting values that are less than those reported for acidified freshwaters. A total of one thousand two hundred and sixteen (1216) fish were netted from eighty-one (81) lakes. Species captured, in order of abundance, were brook trout (62%), ouananiche or landlocked Atlantic salmon (33%), anadromous Atlantic salmon (4%) and brown trout (1%). Catch per unit of effort was correlated to lake pH and surface area while fish presence/absence was related to lake pH. It was estimated that a potential annual fish production of one million kg (in standing waters) and 73,900 anadromous salmon (in river systems) is associated with regions at high risk to acidification. Trace metals including mercury, aluminum, manganese, cadmium, arsenic, selenium, nickel, and zinc were determined in tissue collected from nine hundred and sixty-five (965) fish. Mercury levels ranged from 0.02 to 1.3 ppm with seventy-two (72) specimens exceeding 0.5 ppm. Aluminum and manganese in fish tissue ranged from 0 to 4.6 ppm and 0 to 3.9 ppm, respectively. Other metals were largely in low to undetectable quantities.

Key words: acid precipitation, limnology, salmonids, trace metals, insular Newfoundland.

RÉSUMÉ

Scruton, D. A. 1983. A survey of headwater lakes in insular Newfoundland, with special reference to acid precipitation. Can. Tech. Rep. Fish. Aquat. Sci. 1195: v + 110 p.

Le présent rapport porte sur un levé, mené dans l'île de Terre-Neuve du 16 août au 18 octobre 1981, touchant 109 petits lacs d'amont dont la superficie va de 21 à 2 519 ha. Les paramètres étudiés sont les suivants: morphométrie, chimie de l'eau, zooplancton et nannoplancton, sédiments, benthos et poissons. La chimie de l'eau variait beaucoup selon le lac, la géologie de la roche en place, l'apport d'aérosols marins et les dépôts atmosphériques constituant les principaux facteurs de la variabilité des paramètres chimiques. Le pH lacustre s'échelonnait de 4,90 à 8,39 et, pour dix lacs, il était inférieur à 5,50. L'alcalinité de 93 lacs était inférieure à 200 μ eq L^{-1}, ce qui indique une sensibilité à l'acidification variant de modérée à élevée. Les valeurs de sulfate excédent variaient de 5,7 à 91,4 μ eq L^{-1} (moyenne: 34,5); ces niveaux sont inférieurs à ceux mentionnés pour des lacs ayant des charges atmosphériques modérées à élevées. Les lacs expérimentaux étaient très colorés (moyenne: 48 TCU), ce qui correspond à une acidité naturelle élevée mais complique l'évaluation de l'acidification anthropogénique. Les lacs instables possédaient un surplus de sulfate par rapport au bicarbonate et une insuffisance d'alcalinité par rapport aux principaux cations. Des modèles mis au point par Henriksen portent à croire que l'acidification de cinq lacs peut être reliée aux acides minéraux (dépôt de sulfate) tandis que, dans douze autres lacs, l'acidité organique naturelle est un des principaux facteurs. Les quantités d'aluminium et de manganèse contenues dans l'eau passaient respectivement de 0 à 430 mg L^{-1} (moyenne: 112) et de 0 à 52 mg L^{-1} (moyenne: 13). Ces valeurs sont moins élevées que celles notées pour les eaux douces acidifiées. Au total, 1 216 poissons ont été pêchés aux filets dans 81 lacs. Les espèces capturées, en ordre d'abondance, étaient l'omble de fontaine (62%), la ouananiche ou saumon de l'Atlantique des eaux intérieures (33%), le saumon de l'Atlantique anadrome (4%) et la truite brune (1%). On a établi une corrélation entre les prises par unité d'effort, d'une part, et le pH lacustre et la superficie, d'autre part, tandis que la présence ou l'absence de poisson a été reliée au pH lacustre. Selon l'auteur, une production annuelle potentielle de un million de kg (dans les eaux dormantes) et de 73 900 saumons anadromes (dans les systèmes fluviaux) est associée aux régions à risque élevé d'acidification. Des quantités d'oligo-métaux, y compris le mercure, l'aluminium, le manganèse, le cadmium, l'arsenic, le sélénium, le nickel et le zinc ont été retrouvées dans les tissus prélevés de 965 poissons. Les niveaux de mercure variaient de 0,02 à 1,3 ppm et étaient supérieurs à 0,5 ppm chez 72 spécimens. Les taux d'aluminium et de manganèse étaient respectivement de 0 à 4,6 ppm et de 0 à 3,9 ppm. Les autres métaux étaient présents en quantités faibles ou non décelables.

INTRODUCTION

THE ISSUE

Acid precipitation is a major envionmental concern in many regions of eastern North America, northern Europe, and other global areas. Anthropogenic emissions of sulphur and nitrogen, principally derived from the combustion of fossil fuels, are transported many kilometers downwind of their emission source and returned to the earth as dilute solutions of strong mineral acids and are distributed over a wide geographical area. These acids then interact with the ecosystem and can have devastating effects on the aquatic and terrestrial regimes.

The acidification problem in North America is large in scale affecting, to different degrees, some 5×10^6 square kilometers in eastern Canada and the northeastern United States (Harvey et al. 1981). In Canada, the Atlantic provinces lie in the mid-Atlantic westerlies, a pattern of prevailing winds which places the region immediately down wind of most of North America's major pollution sources. The province of Newfoundland and Labrador lies on the eastern extreme of this zone. Despite being thousands of kilometers removed from major industrial centres in North America, the province is receiving acid precipitation in the range of pH 4.5 to 4.9 and sulphate deposition in the order of 10-20 kg/ha/yr and greater (Whelpdale 1968). It is apparent that the province of Newfoundland and Labrador, despite its non-industrial economic base and geographic distance from pollution sources, is still threatened by acid deposition.

The potential impact of acidic deposition is dependent on the susceptibility of the region and its freshwaters which in turn is primarily governed by the composition of underlying soils and bedrock. Insular Newfoundland, despite its geologic heterogeniety, is characterized by extensive areas that are highly sensitive to acidification (Shilts 1981). In addition large areas of organic (peat) deposits within the province can contribute a natural acidity to surface waters.

The effects of lake and stream acidification on resident fish populations are now a well documented, but nonetheless disturbing, phenomenon (Harvey et al. 1981). In Northern Europe, the Adirondack Mountains of New York, the LaCloche Mountains in Ontario, and in Nova Scotia, fish populations have been eliminated due to the acidification of fresh waters. In Insular Newfoundland, fresh waters are inhabited principally by salmonids; specifically endemic species such as brook trout, sea run and landlocked Atlantic salmon, and relict arctic char. Species such as rainbow trout and brown trout have been introduced (Scott and Crossman 1964). These species represent the range of sensitivity to acid conditions for the salmonid group; with rainbow trout being the most sensitive and brook trout being relatively tolerant; arctic char, Atlantic salmon and brown trout are of intermediate sensitivity (Haines 1981). Already resident fish populations are limited in certain areas by low natural productivity and threatened by overharvesting, poaching, pollution and habitat destruction. An additional threat to resident fish populations is the long range transport of air pollutants and the resulting acidification of sensitive surface waters.

BACKGROUND INFORMATION

The Island of Newfoundland is a large irregularly shaped land mass of some 123,630 square km in the Northwest Atlantic Ocean, lying between 46° and 52° North latitude. The island is a tilted plateau of rolling relief highest on the south and west coast, where elevations can exceed 700 m, and lowest on the northeast coast, where elevations are generally 200 m or less. Rivers and streams on the plateau are of moderate gradient and dominated by large drainage systems, while streams on the Avalon and Northern Peninsulas are of steeper gradients and have smaller drainages. The standing waters in the province can be characterized as intermediate in size with several large dominant lakes and hydroelectric reservoirs. In addition, due to the low relative relief and poorly developed drainage systems in many areas, there are numerous small ponds, bogs or sloughs which are often overlooked as to their potential for fish production. Conservative estimates have determined the area of standing water in the province to be about 12,600 square km or about 10.2% of the land area (MacPherson and MacPherson 1982). Other estimates have considered the amount of surface water in the province, including smaller streams, lakes, ponds and bogs, to be closer to 25% of the land mass (Whelan and Wiseman 1975).

The climate of insular Newfoundland is dominated by three factors; mainly the proximity of a cold ocean environment, the latitude, and the seasonal frequency of contrasting air masses (MacPherson and MacPherson 1982). The island lies in a zone of prevailing westerly winds with seasonal modification due to changing circulation patterns. Winter winds are predominantly westerlies with increasing northerly and easterly flows as spring approaches. Spring and early summer flows tend to be southwesterly returning to predominantly westerly flows in the late fall. Most of the island's climate in areas of moderate relief to sea level is characterized as being cold, snowy, boreal forest type with moderate amounts of precipitation distributed fairly evenly on a seasonal basis. The southwest coast, northern peninsula, and areas of higher altitude are generally colder with only four months having a mean temperature exceeding 10°C. The island's climate is strongly influenced by the Labrador current which, in combination with spring circulation patterns, can considerably delay the spring season (MacPherson and MacPherson 1982).

On a global scale, the island of Newfoundland is characterized as having moderate amounts of precipitation. Precipitation frequency is greatest in the southern portion of the province, particularly upland areas, where measurable precipitation can occur 200-250 days per year and can amount to in excess of 2000 mm per year (Fig. 1). There is a northward gradient in precipitation patterns, as precipitation lessens along the northern regions of the province. There is also considerable modification of precipitation patterns by the Long Range Mountains (MacPherson and MacPherson 1982). While precipitation tends to be well distributed seasonally, there is a tendency for most precipitation to fall between November and March with the spring months (April to June) being the driest. The north coast and Northern Peninsula however can experience wet summers. There is also considerable variation in amounts of precipitation as snowfall and rainfall, particularly in areas of coastal influence. Generally about 75% of the total precipitation falls as rain, with this amount approaching 90% in the south and southeastern areas and falling to about 50% in

northern areas. In many regions, snowfall is discontinuous and accumulation can be highly variable (Peach 1975).

Insular Newfoundland has one of the most complex geological mixes of any North American locale, owing primarly to the tectonic formation of the island during Paleozoic continental drift and collision (MacPherson and MacPherson 1982). This process of drift and collision has led to considerable shear, compression, upheaval, and volcanism which are evident in the geological complexity.

The island is divided into four major geological zones on the basis of geological origin. The Humber Zone occupies the western portion of the province, bordered on one side by the Cabot Fault, and is viewed as the "ancient continental margin" of North America. At the core of this zone is a large area of gneisses, granites, gabbros and anorthosites that are similar to that found in the Canadian Shield in Labrador. In contrast to this, on the western margin of the province and the northern tip of the Northern Peninsula, are carboniferous sedimentary rocks of marine origin, including limestones and dolomites. The eastern portion of the province, labelled the Avalon Zone (and bounded by the Dover Fault), is viewed as being similar geologically to areas in western Europe and northern Africa. This zone contains a basement of volcanic rocks overlain by sedimentary groups. The central region (Gander and Dunnage Zones) is considered to have been formed during an uplifting of the Atlantic Ocean crust during continent formation. Both zones are dominated by large areas of granite intrusions of volcanic origin into metamorphosed sediments. The Gander Zone, in particular, is dominated by gneisses and granites (McKillop 1982).

It is probable that the island was subjected to at least four periods of glaciation of which the most recent, the late Wisconsin period, has destroyed most evidence of previous glacial events. Glaciation, for the most part, has tended to strip the island of most of its overburden, with the glacial debris having been deposited offshore on the Grand Banks. In most parts of the province, only the denuded core with a few highlands remain and glacial deposits are small and localized. Figure 2 illustrates the distribution of major geological types on the island.

The province of Newfoundland is also dominated by extensive areas of organic deposits, having in excess of 2 million hectares of peatlands. These organic deposits are widely distributed but concentrations are evident in high level plateaus and coastal lowlands. Organics can amount to 25-30% of the land types in many of the major river watersheds (Northlands Associates 1982). Surface waters tend to reflect the occurrence of organic deposits, being highly coloured and demonstrating a natural acidity.

A LOCAL PERSPECTIVE OF ACID PRECIPITATION

The acid precipitation problem originates as sulphur and nitrogen emissions which tend to be highly concentrated in eastern North America. In Canada, the Atlantic region produces a relatively small proportion of the nation's acid causing emissions and the province of Newfoundland produces only about 1% of all Canadian emissions of sulphur dioxide and nitrous oxide

(Whelpdale 1968). Major potential pollution sources within the province include pulp and paper mills (Bowaters and Price), thermal generating stations (Holyrood), major industry (ERCO phosphorus reduction plant) and the inactive oil refineries (Come by Chance and Holyrood). None of these sources are considered to contribute significantly to regional deposition and their influence, if any, is extremely localized.

Storm trajectory work by researchers at Memorial University has indicated that much of the sulphate deposited in this region originates in the Ohio River Valley, along the eastern seaboard of the United States, and in southern Ontario. It is apparent that the province is receiving deposition from regions to the west, while the small amount of locally produced emissions effect either local influences or are transported out to sea and, as a result, Newfoundland and Labrador can be considered exclusively a receptor province.

The scale of acid deposition in the province of Newfoundland and Labrador is only now becoming apparent as data is available from existing precipitation monitoring sites (Fig. 3) and through an expanded effort to establish new monitoring stations. In 1977, the Atmospheric Environment Service established precipitation monitoring sites at Gander, Stephenville, and in Goose Bay, Labrador as part of the Canadian Network for Sampling Precipitation (CANSAP). In 1980, the Newfoundland Department of the Environment established two additional monitoring sites at Cape Broyle and at Whitbourne and have since added precipitation samplers at Bay D'Espoir (July, 1981) and near Port aux Basques (November, 1982). The Environmental Protection Service of Environment Canada has established monitoring sites at Gros Morne and Terra Nova National Parks and L'anse au Meadows National Historic Park on the top of the Northern Peninsula.

Precipitation in insular Newfoundland falls in the range of pH 4.5 to 4.9 (mean annual values). There is no clear evidence of a gradient in deposition in a N/S or E/W direction. It is likely the southwest corner of the province is receiving the most acid precipitation (pH 4.5) while the northeast corner the least acid (pH 4.9). The south central region and the Avalon Peninsula are likely receiving precipitation in the range of pH 4.5 to 4.7.

Deposition of sulphate (kg/ha/yr), the dominant ion of concern in acidification, is becoming the widely used standard for interregional comparison. Sulphate deposition in eastern Canada ranges from about 10 to 40 kg/ha/yr and in Newfoundland deposition is in the range of 10-20 kg/ha/yr (Harvey et al. 1981). Much of the province receives in excess of 1200 mm of annual precipitation, amounting to 1.5 to 2.0 times the precipitation received in high deposition regions in central Canada, and can act to narrow the gap in relative loadings.

Present deposition is unlikely to remain constant, and the forecast is for increased levels of emissions, which will translate to increased acidic deposition unless adequate environmental safeguards are put in place. Forecasts have varied from a conservative 8% growth in total emissions to a more pessimistic forecast of 40% growth to the year 2000 (Glass et al. 1981). Of particular concern for Newfoundland is the Nova Scotia Power Commissions's commitment to conversion from oil fired electrical generation to coal fired

generation, resulting in a five-fold increase in coal use over the period 1977 to 1989. Much of this coal use is associated with the Lingan Plant on Cape Breton Island. Emissions for this utility are expected to be transported directly to the highly sensitive south coast region of insular Newfoundland. Modelling efforts by Environmental Protection Service have forecast increases of 2-3% at the insular Newfoundland CANSAP stations, in relation to emissions from this one facility alone.

The Provincial Department of Mines and Energy has produced a sensitivity map of the island (Fig. 4) based on available geological information as a first order evaluation of potential susceptability to acidification. The map indicates that the majority of the island is moderately to highly sensitive with well buffered regions restricted to the west side and top of the Northern Peninsula, and western margins of the island including the Port au Port Peninsula.

In absence of a soils data base, as in Newfoundland, soils are assumed to be derived from underlying bedrock. Glaciation can modify this relationship by distributing the overburden. In Newfoundland glaciation has served to heighten sensitivity by removing much of the overburden. Soils in insular Newfoundland tend to be thin, patchy, high in organic content, low in exchangeable bases and cation exchange capacity; all characterictics of sensitive soil types. Extensive peat deposits are apparent throughout the island with large concentrations in central Newfoundland, the Northern Peninsula, and in the northeast corner of the island. Organic deposits contribute organic acidity to surface waters.

DEPARTMENTAL PROGRAM AND OBJECTIVES

The Department of Fisheries and Oceans (DFO) in the Province of Newfoundland and Labrador has been delegated the responsibility for research and management of freshwater and anadromous fish stocks, and DFO has a constitutional responsibility to provide for regulation, protection and preservation of all fisheries within Canada. In recognition of this mandate DFO has undertaken a departmental program on acid precipitation. The ultimate goals are to protect freshwater and anadromous fisheries resources threatened by acid precipitation and related pollutants and to ensure the long-term maintenance of social and economic benefits associated with this resource.

Initially it was important to determine the scope of the acidification phenomenon problem in potentially impacted regions and develop a national perspective on the problem. In 1981, DFO initiated a national inventory program to obtain a comprehensive data base for a number of lakes in sensitive terrrain to evaluate the regional implications of acid deposition. This inventory program to date has been undertaken in the provinces of Ontario, Quebec, Nova Scotia, New Brunswick, and Newfoundland and Labrador. The program emphasizes common study elements, the utilization of common sampling techniques, and quality control to permit a regional evaluation of the acidification problem.

The goal of this inventory program is to determine the status of lakes and resident biological communities (in particular fish) with respect to acid

deposition and to provide a well defined data base for future (temporal) comparisons. Emphasis has also been placed on determining the contaminant body burden for selected trace metals in fish as a result of atmospheric deposition or as influenced (mobilized) by acidification.

MATERIALS AND METHODS

SELECTION OF LAKES FOR STUDY

A representative sample of study lakes was preselected for survey subject to the following selection criteria. Lakes were located in remote, relatively pristine areas distant from local population centres and point sources of pollution. Lakes selected were generally small, headwater lakes high in the watershed (usually first order lakes with approximately 10% representation of higher order lakes). Lakes were generally distributed around the island with a slight bias to include more lakes in geologically sensitive terrain and in areas receiving higher deposition (e.g. lakes along the south coast).

Certain field criteria were established to assist in assessing the suitability of selected lakes for sampling. Excessively shallow lakes (<3m) with extensive bog drainage or highly coloured water, lakes with clear cut or burned over areas in the watershed, lakes whose water levels were regulated, and lakes with extensive cottage development were not selected. Field selection criteria had to be somewhat loosely applied due to the preponderance of highly coloured and/or shallow (>3 m) lakes. In order for the sample to be more representative a large number of the above lake types were included in the survey.

Ten lakes were selected for detailed morphometry, including bathymetric mapping and calculation of volume and mean depth. These ten lakes were selected to represent all geological types, different classes of WA:LA ratio, and to coincide with lakes in which a large sample of fish (up to 50 individuals) were available for tissue analysis.

A total of 109 preselected lakes were successfully sampled from August 20 to October 18, 1981. The study lakes generally represented the whole of the island with the noteable exceptions of the Burin Peninsula (2 preselected lakes were not visited) and the Avalon Peninsula. Study lakes were located in remote areas and, with the exception of a few, were inaccessible by road. Field personnel and sampling equipment were transported to the study lakes by float equipped deHavilland Beaver aircraft and Bell Jet Ranger helicopter. At each lake a standard set of field sampling techniques were routinely conducted.

LAKE MORPHOMETRY

Lake surface area, watershed area, lake elevation and distance from the coast (nearest salt water) were determined for all 109 ponds. Lake surface area and watershed (drainage) area were measured on 1:50,000 topographic maps with a compensating polar planimeter. Lake elevation was also estimated from topographic maps. Distance from the coast was determined on a 1:1,000,000 scale map of insular Newfoundland.

Ten (10) ponds were selected for detailed morphometry. Several depth transects were taken at each selected pond using a Raytheon DE719B depth sounder with transducer mounted on an inflatable Zodiak boat. Fix marks were recorded to permit positioning of transects for bathymetric mapping and subsequent volume calculations. Bathymetric maps, with 5 m contour intervals, were prepared. Lake volume was calculated according to Welch (1948).

WATER SAMPLE COLLECTION

Initally, a water sampling station was established at or near the midpoint of each lake. A temperature profile, at 1 m intervals, was taken using an Intersil AD 590 temperature transducer linked to a Raekit 3200 D digital thermometer (accurate to 0.1°C). Surface water temperatures for the calibration of the thermister were read from a precision nitrogen over mercury column thermometer. Secchi depths were determined by lowering a 30.5 cm diameter disc along with the transducer. This vertical cast also permitted a sounding of the sampling location.

A water sample was collected from each lake for subsequent detailed laboratory analysis. In shallow lakes (3m or less) water was dipped 0.5 m below the surface. In all other lakes, water was collected with a tube sampler in accordance with procedures outlined in the Ontario Ministry of Natural Resources Manual (1980). A surface dip was routinely used to collect the sample for trace metals analysis.

The water sample was then subdivided into various prelabelled containers as required for field and laboratory analysis. Samples for alkalinity and field pH were stored in 500 ml linear polyethylene (LPE) Nalgene bottles while a 250 ml LPE Nalgene bottle was filled for subsequent major ion analyses. A 250 ml LPE Nalgene bottle, acid washed and pre-acidified with 2 ml of nitric acid prior to field collection, was used to collect the sample for trace metals analysis. All LPE Nalgene bottles were stored in a refrigerated cooler at 4°C until field analyses were completed or until samples could be shipped to the analytical laboratory. Samples for ortho-phosophate, NO^{-3}, Cl^{-1} and SO^{-4} were collected in four new LPE scintillation vials (20 ml) and frozen upon arrival at the mobile field laboratory.

Samples for the determination of dissolved gases (CO_2 and O_2) were collected in 300 ml Biochemical Oxygen Demand glass bottles. The sample for CO_2 analysis was kept cool (no preservation) until analyzed. The dissolved O_2 sample was preserved in the field with of 1 ml of manganous sulphate and 1 ml of alkaline iodide, then stoppered and shaken. A second mixing was performed at the field laboratory prior to storage in the cooler.

FIELD WATER CHEMISTRY

Lake water samples were routinely analyzed for pH, dissolved carbon dioxide, dissolved oxygen and alkalinity at the mobile field laboratory. A Fisher Accumet 119 portable pH meter (digital), accurate to 0.01 pH unit, and with a gel-filled plastic bodied combination glass/reference electrode, was

used for all field measurements of pH and for potentiometric titrations. The pH meter was calibrated daily prior to the start of field and laboratory routines using standard reference buffer solutions (pH 4.0, 7.0).

Samples for alkalinity determination were stored, cooled, and then warmed to room temperature for analysis, always within 24 hours of collection. A 100 ml aliquot of sample was drawn off and transferred to a 250 ml beaker. After recording the initial pH, small amounts of H_2SO_4 (0.01N) were delivered using a Canlab repipet (with an accuracy and reproducability of ±1%) and the resulting change in pH recorded. A minimum of 30 readings in the pH range of 5.5 to 3.5 were obtained (Ontario Ministry of Natural Resources 1980). Alkalinity was later calculated from the data set obtained by the Gran titration according to a modified computer routine.

Samples for free carbon dioxide determination were kept cool and in the dark, and were analyzed within 12 hours of collection. Fee CO_2 was determined by potentiometric titration of a 100 ml sample with sodium carbonate to a fixed end point of pH 8.3, using method 407B as described by the American Public Health Association et al. (1975). The initial pH reading obtained in each titration was taken as the field pH for that lake.

Samples for determination of dissolved oxygen, once fixed, were stored in a cooler for up to 6 weeks prior to analysis. Determination of the dissolved oxygen content was carried out using the standard Winkler titration which is a colorimetric titration as described by the American Public Health Association et al. (1975), method 218A.

LABORATORY ANALYSIS OF WATER SAMPLES

Water samples were shipped from the mobile lab by air to the selected analytical laboratory. Samples were kept cool in insulated coolers during shipment, while nutrient sample vials (one each for sulphate, chloride, orthophosphate and nitrate) were kept frozen. A list of the analytical procedures used to determine all required water sample parameters and tne limit of detection is provided in Table 1. All methods follow those outlined in Environment Canada (1979) and American Public Health Association et al. (1975). Conductivity was measured by a Radiometer Conductivity Bridge (CDM 2e) in microsiemens per centimeter (µs/cm). A radiometer model 26 combination glass/reference electrode pH meter was used to determine lake water pH to an accuracy of ±0.01 units. Sodium, potassium, calcium and mangnesium concentrations were determined by direct aspiration using atomic absorption spectrophotometry. Colormetric determinations, using a Technicon Auto Analyzer were used for the following elements: alkalinity, sulphate, chloride, orthophosphate and nitrate. Colour was determined by visual comparison with platinum colour plasma, while turbidity values were obtained from a Hach nephelometer (model 2424). Trace metal content was determined using atomic absorption spectrophotometry. Aluminum, cadmium, copper, nickel, lead and zinc concentrations were measured by the Atomic Absorption - Heated Grpahite Atomizer (HGA) method, while iron and manganese required the Inductively Coupled Plasma (ICP) method. In our study, lake water was analyzed for aluminum, manganese, lead, iron, and cadmium in all lakes (n = 109) and for

copper, zinc, and nickel in a cross section of lakes (n = 18). Excess or non-marine concentrations of sulphate, sodium, potassium, calcium and magnesium were calculated from the ratio of these ions to chloride in sea water and the concentration of chloride in each lake according to the equations provided by Watt et al. (1979).

The sum of anions (Cl, SO_4, HCO_3), cations (Ca, Mg, Na, K), constituents (as mgL^{-1}), and percent difference between anions and cations were calculated as a check on analytic quality. An EPA standard reference sample and three blind batches of lake water samples were also analyzed by participating labs to permit an interlab comparison of data.

PLANKTON SAMPLE COLLECTION

A zooplankton tow was carried out at each lake using a Wisconsin type plankton net with a 20.5 cm diameter opening, mesh size of 64 μ, and overall net length of 1.2 m. A vertical tow was made over the water quality station established at each lake from a depth of 1 m above the maximum depth of the sampling station. In lakes 2 m or less a horizontal tow of approximately 1 m was made. The mesh and cod-end bucket were thoroughly rinsed to concentrate all organisms. Samples were preserved with 25 ml of buffered formalin and stored in 500 ml glass jars.

A surface water sample was collected in a 500 ml glass jar from each lake for nannoplankton analysis. The sample was fixed immediately with Lugol's iodine solution and stored for subsequent analysis.

SEDIMENT AND BENTHOS COLLECTION

Bottom sediment samples were collected in the vicinity of the water sampling station at each lake using a 22.8 cm^3 Birge-Ekman dredge. Five grab samples were obtained from the profundal region of each lake where bottom sediments were condusive to sampling. Samples were not collected from 26 lakes because of rocky substrates.

The grab samples were retained in plastic bags in the field and returned to the mobile field laboratory. From one grab a 100 ml subsample was taken, frozen upon return to the mobile lab, and retained for subsequent chemical analysis. In addition, the sediment/water interface pH was taken from one of the grabs, while intact in the Ekman dredge, at a depth of 2 cm using a Fisher Accumet 119 pH meter.

At the mobile field laboratory the grab samples (5) were washed through a 0.5 mm screen, and examined for benthic invertebrates. The residue from each sample was thoroughly examined and all macroscopic organisms were removed and placed in labelled 20 ml vials. Each sample was then preserved with 75% ethanol and retained for subsequent analysis.

FISH COLLECTION AND SAMPLE ANALYSIS

A multifilament surface floating gill net, 107.1 m long and 1.8 m deep consisting of seven 15.3 m panels of mesh sizes 3.8, 5.1, 6.4, 7.6, 8.9, 10.2 and 12 cm (stretched measure), was set at each lake with suitable sampling depth. The net was attached to shore (with smallest mesh inshore), set perpendicular to the lake shoreline, and the offshore end was anchored and marked with a float for retrieval. Selection of the optimum location for setting of the net was determined during the reconnaissance pass made by the aircraft prior to landing. Prominent points of land near major inlets or outlet were preferred locations but frequently other sampling constraints such as wind direction and rock outcrops determined net locations.

Nets were set at least overnight or for a maximum of two days. On occasion, due to weather grounding of the aircraft, nets were left fishing in excess of two days (and on one occasion up to 108 h). The net was routinely

retrieved from the offshore end (largest mesh). Fish were removed from the net, sorted into bags by panel, and retained for subsequent analysis.

Analysis of fish samples was performed at the mobile lab within 12 hours of collection. Each fish was identified as to species and given a consecutive specimen number. Fork lengths (to the nearest mm) were measured on a standard measuring board and wet weights (to the nearest g) were determined on an Ohaus model 710 triple-beam balance. Scale samples were collected from above the lateral line and slightly back of the dorsal fin on each fish. Otoliths were collected from a stratified sample (by length) of 100 brook trout to allow for a comparison of aging techniques. Sex and maturity were determined from a visual examination of the gonads.

After examination each fish was gutted, the head and tail removed, and the remainder was bagged for freezing and subsequent shipping to the fish tissue chemistry laboratory. From each pond a stratified sample (by length) of up to 15 specimens of the preselected type species (brook trout) were retained, while at 12 designated ponds as many as 50 fish were selected for tissue analysis.

ANALYSIS OF METALS IN FISH TISSUE

Fish tissue samples, upon arrival at the analytical laboratory were thawed, filletted (skin and bones removed) and refrozen. For each tissue sample (dorsal musculature) a 20 g portion was double wrapped in aluminum foil and baked at 350°C overnight to be used for lipid determination. Another 20-50 g sample was homogenized with a Polytron PT 10-35 homogenizer equipped with a teflon fitted probe generator.

Two digestions of fish tissue homogenate were required for determination of trace metal content. A nitric/sulphuric acid digestion followed by a permanganate/persulphate digestion was required for mercury analysis, while a nitric/perchloric/sulphuric acid digestion was carried for all remaining metals (arsenic, selenium, zinc, cadmium, nickel, aluminim, iron, and manganese).

The nitric/sulphuric procedure for mercury is described by Environment Canada (1980). The nitric/perchloric/sulphuric digestion followed the procedure of Agemian and Thompson (1980) with some slight modification. To improve the detection limits for manganese and aluminum, part of the nitric/perchloric/sulphuric digest was concentrated five-fold. The procedure used for determination of lipid content of fish homogenate is described in Bligh and Dyer (1959).

Metal concentrations in the fish tissue digests were measured with a Varian AA475 Atomic Absorption Spectrophotometer using procedures outlined in Environment Canada (1979). The analytical procedures employed for the fish tissue analysis, detection limits and the concentration of standards used to calibrate the spectrophotometer are provided in Table 2.

QUANTIFICATION OF FRESHWATER HABITAT AND ASSOCIATED SALMONID RESOURCES AT RISK

In order to obtain a first order approximation of potential impacts of acidification on freshwater and anadromous fisheries resources, freshwater habitat and associated fish resources in high risk areas were estimated. The geographical areas of concern were delineated on the basis of lithological sensitivity (Shilts 1981) and current lake status (study results). The boundaries of these regions corresponded to ecodistrict boundaries as determined by biophysical interpretation (Northlands Associates 1982). The quantification of land area in the regions of concern were determined by summing the land area for the associated ecodistricts. Estimates of standing freshwater were available from two sources: the biophysical data base (Northlands Associates 1982) and as determined by occular estimation (Whelan and Wiseman 1975). Fisheries production potential were detemined for both estimates of standing freshwater habitat. The biophysical data base is considered most reliable owing to the finer scale of map products used in interpretation (airphotos of 1:12,500 scale as opposed to topographical maps at a scale of 1:50,000).

The fisheries production potential of standing waters at risk was estimated acording to Ryder (1965). A potential annual yield of 3.65 kg/ha/yr. (3 lbs./acre/yr.) as determined for 38 Avalon Peninsula lakes (Whelan and Wiseman 1977) was applied to calculated freshwater habitat at risk.

Estimates of river habitat and the associated potential production of anadromous Atlantic salmon in the areas of concern were extracted from the Resource Development Subcommittee Report for the Atlantic Salmon Task Force (1978). The boundaries of the regions of concern generally corresponded to statistical sections. Summaries of productive river habitat (accessible and inaccessible) and potential production of salmon (grilse and large salmon) by section were totalled. Biological data used to estimate production potential, including egg deposition requirements, grilse:large salmon ratio, smolt production, sea survival rate as well as commercial and recreational exploitation rates is contained in the Resource Development Subcommittee Report, Appendix B.

RESULTS AND DISCUSSION

A total of 115 lakes were visited during the survey. Of this total, 109 lakes were successfully sampled for water quality and biological parameters, with 6 lakes precluded from sampling on the basis of selection criteria. Bottom samples (for sediment and benthic analysis) were obtained from 86 lakes, as substrates in 23 lakes were too hard for the sampling apparatus. Fish were collected from 81 of 108 lakes that were netted. Plankton samples (zoo- and nanno-) were collected from all 109 study lakes.

The distribution of study lakes by region is as follows: Northern - 23, Central - 20, Eastern - 22, Southern - 24, Western - 7, and Avalon Peninsula - 3 (Fig. 5). The Avalon Peninsula was not designated for intensive sampling due to the large lake and fisheries data base that exists for that region.

GENERAL LAKE CHARACTERISTICS

Lakes sampled ranged in size from 21 to 2519 hectares (mean of 153 ha) and the distribution of lakes by size class is presented in Figure 6. It is initially important to point out that lakes have been divided into clearwater lakes (color value of 15 or less) and brown water lakes (color values greater than 15) to assist in any evaluation of organics in relation to lake chemistry of morphometry. Sixty-five lakes (60%) ranged from 11 to 100 ha, 41 (38%) from 101 to 1000 ha, and 2 (2%) were in excess of 1000 ha. All selected lakes were located high in their respective drainage systems, with 98 (90%) first order lakes, 8 (7%) second order lakes, 1 (1%) third order lakes, and 2 (2%) fourth order lakes.

Lake elevations ranged between 24 and 709 m above sea level (mean of 248 m) with 16 (15%) less than 100 m, 84 (78%) between 100 and 500 m, and 8 (7%) greater than 500 m (Fig. 7). Lake elevations generally reflect the moderate relief of the province and all high elevation lakes were restricted to the Long Range Mountains. Elevation and quantity of precipitation largely control runoff levels and high elevation lakes would generally have higher slopes. The majority of lakes were located varying distances from the sea coast, ranging from 3 to 87.5 km (mean of 24.5 km).

Most of the study lakes had a relatively low watershed to lake area ratio (WA:LA) with ratios ranging from 2.5 to 36.2 (mean of 8.4) with the higher ratios generally contributed by the larger lakes. It is apparent in Figure 8 that 75% (or 81 lakes) had ratios at less than 10:1. The WA:LA ratio is an important feature of sensitivity to acid precipitation governing interaction between acidifying (depositional) and buffering elements, with lakes with low ratios being relatively more sensitive.

Mean depths for 10 lakes preselected for bathymetry ranged from 1.3 to 12.9 m. Maximum depth was determined for all lakes sampled and ranged from 1.0 to 29.0 m. It should be noted that accurate estimation of maximum depth is only possible for lakes with bathymetric information and for the other 98 lakes, maximum depth was a measure of depth at the water sampling station. Fourty-one (38%) of the lakes had "apparent" maximum depths of less than 3 m.

Lakes were sampled from 7 of 9 major geological zones delineated for the island portion of the province. Sixty-two lakes were located in highly sensitive geological regions (granites, gneisses, volcanics), 26 lakes in high to intermediate sensitivity geotypes, and 8 lakes located in areas of low sensitivity. The remaining 17 lakes were unclassified due to the occurrence of two or more geological types of different sensitivity within their watersheds.

Surface water temperatures varied from 5.6°C on October 12 to 21.8°C on September 5. Temperature profiles (at one meter intervals) were obtained at each lake over the water quality sampling station. The sampled lakes showed little evidence of thermal stratification with only 4 of 108 lakes demonstrating a clear thermal gradient and true thermocline. These four lakes were small in size (29 to 140 hectares) but were above the average maximum depth (11.6 m). It is apparent that these lakes were of sufficient depth to restrict complete wind induced circulation of waters while their volumes were small enough to allow sufficient warming of surface layers to permit stratification. These four lakes are classified as second class with respect to thermal stratification (stratified but with bottom temperatures greater than 4°C) while the remaining lakes are considered third class, that is no stratification (Hutchinson, 1957).

Secchi disc depth, as a measure of light penetration, was determined at all ponds. Secchi depths ranged from 0.3 to 9.5 m (mean of 2.7). In many of the shallow lakes (34 or 31%) the secchi disc was still visible at the bottom of the pond. In these lakes, the entire water body could be considered in the euphotic zone (Hutchinson 1957). In the remaining 75 ponds, where the secchi disc did not reach bottom, secchi depths ranged from 0.3 to 7.5 m (mean of 2.95). In the remaining lakes, Secchi disc depth was strongly correlated with water colour ($r = -0.66$) and with turbidity ($r = -0.62$), two factors that determine the absorption of light in a water column (Hutchinson, 1957). Kerekes (1981) also reports that highly coloured and/or turbid waters restrict the trophogenic zone and the potential primary production. Turbidity values (JTU) ranged from 0.22 to 3.10 with a mean of 0.65 JTU. Values exceeding 1.0 were common (16 lakes). Kerekes (1980) has correlated the high turbidity in shallow ponds in Newfoundland to the ability of wind driven circulation to resuspend particulate matter available in lake sediments. This is certainly a plausible explanation for the high amount of turbid waters in our study considering the number of small, shallow, exposed ponds in the sample. Turbidity is also strongly related to surface runoff with high turbidities during high runoff periods (Environment Canada 1979).

A significant feature of insular Newfoundland lakes is the high colour of the waters. A colour value of 15 (TCU) was arbitrarily chosen to distinguish between true clearwater lakes and brown water lakes (P. Dillon, J. Kerekes, pers. comm.). As a result, 17 lakes (16%) were classified as clear water lakes (0-15 in colour) while the remaining 92 lakes (84%) were considered to be brown water lakes (colour values from 16 to 225) (Fig. 9). Thirty-five lakes (32%) had colour values in excess of 50 and could be considered highly coloured. Colour is a good indicator of dissolved organic matter in water (Hutchinson, 1957) and the division of lakes into clear water, brown water, and highly coloured was performed to assist in the evaluation of the role of weak organic acids in the acidification phenomenon.

Clearwater lakes in insular Newfoundland are usually headwater lakes, with a low relative basin size (watershed area to lake area ratio) and hence the likelihood of organic deposits in the watershed is small (Kerekes, 1978). The clear water lakes in this study were first order lakes with watershed to lake area ratios from 2.2 to 16.6 (mean of 6.4), somewhat less than the average for the entire sample. Most of the clear water lakes were located along the Northern Peninsula, many in the well buffered geotypes (limestones, dolomites). Stumm and Morgan (1981) report that humics precipitate in the presence of major cations (calcium and magnesium) so water with high catonic content ($>10^{-3}$ M) often contain little humic substance and hence little colour. Clear water lakes were also apparent in the igneous geotypes in the higher elevations. Kerekes (1978) found that high elevation lakes in Gros Morne National Park with considerable basin size were clear water type, due to the absence of organic deposits at higher elevations.

LAKE WATER CHEMISTRY

The relative proportion of major ions in the study lakes varies considerably and reflects three major determinants; the underlying bedrock geology and associated overburden, atmospheric inputs of marine origin, and the atmospheric input of anthropogenic pollutants. The relative contribution of each of these factors is related to the intensity of each factor and can be considered a dynamic interaction of acids and bases. Atmospheric inputs of sea water salts are supplying most of the chloride ion and much of the sodium ion to surface waters in Newfoundland (Kerekes and Hartwell 1980) while anthopogenic sources are implicated in supplying much of the sulphate ion present and associated hydrogen ion to dilute surface waters (Harvey et al. 1981). Carbonic acid and/or mineral acid weathering of the lithological components is considered to supply most of the calcium, magnesium and bicarbonate ions (Hem 1970).

The sum of constituents (or salinity) is a measure of the total of major ionic constituents in lake water. Values for the study lakes ranged from 4.4 to 96.7 mgL^{-1} (mean of 12.8 mgL^{-1}). This mean value is very low by global standards (Armstrong and Schindler 1971) and emphasizes the dilute nature of much of Newfoundland's freshwaters, even more so when considering that the contribution of marine constituents to freshwaters is considerable. This mean value is very close to that reported for 40 lakes in the Experimental Lakes Area on the Canadian Shield (12.5 mgL^{-1}), and would place Newfoundland's lakes among the softest in the world (Armstrong and Schindler 1971). The world average is in the order of 112 mgL^{-1} (Livingstone 1963). Generally lakes underlain by igneous rocks far from the coast were the most dilute. Lakes underlain by gneisses, granites and volcanics had mean salinities of 6.7, 9.8 and 10.7 mgL^{-1}, respectively, with marine constituents contributing between 38 and 57% of the total (on an equivalent basis).

Geological Influences

The relationship between water chemistry and geochemistry is most apparent when examining the relative chemical composition and ionic dominance of lakes within each geotype (Fig. 10). Sodium or calcium were the dominant cation in

all lakes with magnesium and potassium of lesser importance. Calcium and magnesium are commonly found in association, and calcium is routinely the dominant ion (Faust and Aly 1981). When considering non-marine or "excess" concentrations of major cations only, calcium is the dominant cation in all geotypes. Lakes underlain by limestones, gabbros and volcanics were all calcium dominated (Ca > Na > Mg > K). Sodium ion was dominant (Na > Ca > Mg > K) in the lakes underlain by granites, gneisses, siltstones, and the conglomerates/sandstones geotype. With the exception of one lake underlain by conglomerate/sandstone, the remaining lakes in these other three geotypes are considered highly senstitive to acidification. Sodium of geologic origin is present in most surface waters, usually in concentrations less than calcium and magnesium, but in regions of strong marine influence and with naturally dilute waters, sodium can become the dominant cation (Faust and Aly 1981).

It was surprising that lakes underlain by granites were not more dilute, and it was expected that the ionic composition of granitic lakes would approximate that of the lakes underlain by gneisses. Most of the lakes in this geotype (37 or 82%) did have calcium concentrations of less than 50 μ eq L^{-1}. The remaining eight lakes had calcium concentration greater than 50 μ eq L^{-1}, ranging up to 419 μ eq L^{-1}. The two lakes with highest calcium levels (275, 419 μ eq L^{-1}) were located in the western region and it is suspected that glacial till in these areas, on the eastern slope of the Cabot Fault, may contain carbonates (Neale 1971). This is an example of the overburden, or glacial drift, not reflecting the chemical constitution of the underlying bedrock. It is conceivable that the other six lakes may also contain a source of bicarbonate in their watersheds. As a result these eight lakes make the granitic geotype appear somewhat less sensitive than expected.

Chloride was the dominant anion in lakes in four geological regions, (conglomerate/sandstone, siltstone, granites and gneisses), correlating with the geotypes in which sodium was the dominant cation. The order of dominance was $Cl^- < HCO_3^- < SO_4^{-2}$, except in the lakes underlain by gneisses, where sulphate was the second most important anion ($Cl^- > SO_4^{-2} > HCO_3^-$). Chloride and sodium ion are highly correlated for the entire data set ($R = 0.96$) and the dominance of these ions in dilute waters points to the important contribution of marine aerosols to surface water chemistry in insular Newfoundland. In contrast, lakes underlain by igneous rocks on the Canadian Shield, exposed to precipitation with little marine influence, are dominated by calcium and by bicarbonate and/or sulphate (Armstrong and Schindler 1971).

Bicarbonate ion was dominant in the remaining geotypes (limestones, gabbros, volcanics) in the order $HCO_3^- > Cl^- > SO_4^{-2}$ also corresponding to lakes dominated by calcium. Bicarbonate ion and calcium ion were highly correlated ($r = 0.90$) as is expected stoichiometrically when the primary source for these two ions is from weathering of soils and bedrock. The importance of ions of marine origin (Na^+, Cl^-) is reduced in these readily weathered geological types. Very high bicarbonate (and calcium) levels were observed in the lakes underlain by limestones and dolomites, illustrating the ready availability of calcium carbonates in these watersheds and the large potential buffering ability afforded these lakes.

For ions whose primary source is weathering of bedrock and soils, there is good agreement between the spatial distribution of parameter values and the occurrence of geological types (Fig. 2). Distribution maps for calcium (Fig. 11) and magnesium (Fig. 12) demonstrate lowest values are associated with the igneous geotypes, while lakes situated in sedimentary or metamorphic regions have higher concentrations of these two major cations, with highest values associated with the limestone and dolomite geotypes. Bicarbonate ion distribution, as indicated by field alkalinity (Fig. 13), is very similar to calcium distribution.

Contribution of Marine Aerosols

The atmospheric entrainment of ions of marine origin and deposition to insular Newfoundland lakes is considerable, deposited either as aerosols or in precipitation. The relative contribution of marine salts is largely a function of the distance of a water body from the sea, the pattern of prevailing winds, precipitation patterns, and topography (Henriksen 1981). Sea salt aerosols fall out in dry deposition rapidly and are readily washed out by precipitation, resulting in a sharp coastal gradient (Wright et al. 1977).

The two dominant ions associated with marine deposition, chloride and sodium, demonstrated good correlations with distance from the coast, $r = 0.60$ and 0.59, respectively. Distribution maps for these two parameters (Fig. 14 and 15) clearly illustrate a sharp coastal gradient. The influence of the prevailing westerly winds and topography is also apparent with higher values along the western margins of the province, with highest values in the southwest corner of the province, an area receiving the highest annual precipitation in the province (Yoxall 1980). Studies in Nova Scotia indicate that about 80% of the deposition of marine aerosols is within 20 km of the coast (Ogden 1982).

Chloride ion, in remote regions unaffected by man's influences (i.e. uninfluenced by road salts), is considered to be entirely contributed by marine aerosols while sodium is also predominantly of atmospheric origin. Other major cations including calcium, magnesium and potassium are also contributed by marine aerosols although terrestrial sources are usually the major contributors. Sulphate is also largely deposited by atmospheric deposition, originating from both marine and anthropogenic sources. To evaluate the sea salt influence, and later to examine acidification, it was necessary to determine the non-marine or "excess" concentrations of the above ions. The marine contribution was calculated on the basis of the ratio of calcium, magnesium, sodium, potassium and sulphate ions to chloride in salt water. From the measured levels of chloride in each lake, the marine contribution of each ion was then determined. The marine component was then subtracted from the measured ion concentration in each lake to determine "excess" values (Watt et al. 1979). The relative contribution of ions of marine origin was as follows: chloride - 100%, sodium - 60%, potassium - 55%, sulphate - 26%, magnesium - 12% and calcium - $<1\%$.

Anthropogenic Inputs

Four principal ions of concern in relation to atmospheric deposition of anthropogenic pollutants include hydrogen (H^+), nitrate (NO_3^{-2}), ammonium (NH_4^+) and sulphate (SO_4^{-2}). The relationship between the input of ammonium and nitrate ions and concentrations in surface waters is difficult to assess because of the variety of mediating biological and chemical processes in the natural environment. Much of the deposition information for these ions is uncertain and concentrations may vary considerable between collection and analysis (Harvey et al. 1981). In addition, it is accepted that nitrogen compounds are more readily washed out of the atmosphere than are sulphates and hence are deposited closer to emission sources (Whelpdale 1978). Sulphate on the other hand is a relatively conservative element in natural systems and hydrological pathways tend to dominate biological processes. It has demonstrated that marine precipitation is dominated by sulphuric acid (H_2SO_4) while continental precipitation tends to be dominated by ammonium sulphate ($(NH_4)_2SO_4$) (Ogden 1982).

The distribution map for total sulphate (Fig. 16) shows the importance of atmospheric inputs in determining sulphate levels in lakes. Lakes in coastal regions, particularly along the west coast have relatively higher sulphate values than other study lakes. This is not surprising considering that marine sources account for 26% of the ion (for all lakes combined) and for a higher proportion in systems near the coast.

Values for "excess" or non-marine sulphate were mapped (Fig. 17) to evaluate exclusively the anthropogenic inputs of the ion. The long range transport of sulphate is associated with smaller particles and also gaseous forms (SO_2) which settle out more slowly and are transported farther inland than is sulphate entrained from marine aerosols (Wright et al. 1977). The map of excess sulphate demonstrates a more even distribution with respect to a coastal gradient and the influence of meteorological patterns and topography is more apparent. Highest concentrations of (40 - 90 μ eq L^{-1}) are evident in the western and southwestern regions of the province and there is a general west to east concentration gradient. Prevailing wind patterns (mostly westerly) and the higher elevations associated with the Long Range Mountains appear to be dominating the pattern of excess sulphate deposition.

The distribution of excess sulphate in lake water does generally agree with what is conceived to be the pattern of acidic deposition in the province (as indicated by rainfall pH). The southwest corner of the province, with sulphate values ranging from 50-90 μ eq L^{-1}, is thought to be receiving rainfall of pH 4.5. This region also receives the highest annual precipitation (120-175 cm) and the highest annual runoff (150-208 cm) (Yoxall 1981). Eastern areas, in particular the Avalon Peninsula, have the lowest excess sulphate values, between 10 and 20 μ eq L^{-1}, although the sample size is small. Unfortunately there is insufficient depositional information for insular Newfoundland, particularly in spatial terms, to permit a rigorous comparison between precipitation inputs of sulphate and concentrations in lake water. Regions that have an established and well distributed precipitation monitoring network and tend to be geologically homologous have demonstrated good

correlations between anthropogenic inputs of sulphate and levels in freshwaters (Aylmer et al. 1978; Gjessing et al. 1976).

There are certain anomalies in the map of excess sulphate that cannot be explained by atmospheric inputs. Lakes in three geographical locations (specifically central Newfoundland, west of Flat Bay, and between Grand Lake and Red Indian Lake) show extremely high "excess" sulphate relative to the surrounding areas. It has been suggested that there is a component of sulphate in these lakes that is of geological origin, likely due to the occurrence of sulphur bearing minerals such as pyrite or gypsum (P. Davenport, pers. comm.). As iron is often associated with these minerals, a comparison of the distribution maps for "excess" sulphate and iron (Fig. 18) indicates there is good evidence for geological input of sulphate to lakes in these regions. Environment Canada, Water Quality Branch found similar sulphate anomalies in their regional survey of Newfoundland lakes in the fall of 1980 (T. Clair, pers. comm.).

Although excess sulphate is assumed to be all of anthropogenic origin, there are other potential sources for the ion, including the aforementioned geological inputs. Work in Ontario on Canadian Shield lakes has suggested that there may be natural background levels of sulphate of biological origin in lake water, perhaps as much as 30-60 μ eq L^{-1} (Harvey et al. 1981). Similarly Aylmer et al. (1976) has suggested background levels for sulphate of 20-60 μ eq L^{-1} for Swedish lakes. Work in calibrated watersheds in Nova Scotia has indicated that organic deposits may act as sulphur reservoirs and under certain conditions, sulphur can be reduced to sulphate and transported to lake waters (Kerekes et al. 1982). Sulphate has been highly correlated to colour and organic carbon in three Nova Scotia lakes further suggesting sulphate release from bogs. Input from bogs or organic soils can be largely related to periods of high runoff and as a result, can be a seasonal phenomenon (Harvey et al. 1981). Another consideration, as reported by Henriksen (1981), Kerekes (1982), and others, is that the automated colourimetric method for sulphate determination (as used in this study) can lead to overestimates for the ion in highly coloured waters, particularly in waters with colour values in excess of 50. This can lead to a possible excess of anions in the ion balance as cation determination is unaffected by humics. Environment Canada is actively researching colorimetric interference in the automated method for sulphate determination, with the aim at minimizing interference or possibly correcting historical data in colored waters for this problem (M. Thompson pers. comm.). All of these concerns are relevent when considering excess sulphate in relation to anthropogenic deposition and the acidification process.

Values for "excess" sulphate in insular Newfoundland ranged from 5.7 to 91.4 μ eq L^{-1} with a mean of 34.5 μ eq L^{-1} (Fig. 19). A high proportion of the lakes (81%) had values between 20 and 50 μ eq L^{-1} and 5 of the 10 lakes with values in excess of 50 μ eq L^{-1} were associated with potential geological sources for the ion. Excess sulphate values for Newfoundland lakes are compared with others in eastern North America region in Figure 20. It is apparent that sulphate levels in the study lakes are less than those in areas experiencing acidification damage, specifically southern and central Ontario, where sulphate levels range from 100 to over 300 μ eq L^{-1}. Levels in the study lakes are similar to other regions of Atlantic Canada, and similar to those

previously reported for Newfoundland (Kerekes 1978; Kerekes and Hartwell 1980).

Recent published information for freshwater (non-marine) sulphate in Newfoundland and Labrador lakes show there is generally good agreement with the results of this study. Lakes in Gros Morne National Park (Kerekes 1978), on the west coast of insular Newfoundland, demonstrated the highest values for excess sulphate, which is consistent with our sulphate distribution map (see Fig. 17) and with considerations of meteorology and topography. Sulphate levels in our lakes were marginally less than those reported for the Water Quality Branch survey of lakes in 1980 (T. Clair pers. comm.). This difference may be attributable to temporal variations, as the WQB study was conducted in November, a historically high runoff period, while our study was conducted in a low runoff period (mid-August to mid-October). Excess sulphate levels in L'anse au Meadows National Historic Park (Kerekes and Hartwell 1980) at the northern tip of the province, are extremely low and are very similar to those previously reported for Labrador (T. Clair pers. comm.), suggesting perhaps a north to south gradient in deposition along the Northern Peninsula. Low sulphate values in Labrador have been attributed to apparent low deposition and have been suggested as possibly representing natural "background" levels (Harvey et al. 1981).

Lake pH

pH values for the study lakes were determined at three different times. Initial pH readings were obtained during determination of carbon dioxide and total inflection point alkalinities and were both subsequently considered to represent field measured values. The initial pH during CO_2 determination was eventually taken to best represent field pH, owing to the minimum duration between collection and analysis (always less than 12 hours). Henriksen (1981) and Strumm and Morgan (1982) have both reported on this instability of pH between collection and analysis which can influence the interpretation of the results. Values for pH (lab pH's) were also determined during routine analysis in the analytical laboratory. Field pH values were found to be consistently higher than laboratory measured values. Field measured values were taken to be most representative of ambient conditions, owing to the importance of aqueous carbon dioxide in natural systems, and were used in all subsequent evaluation of pH.

Field pH values ranged from 4.90 to 8.39 with 2 lakes (2%) having pH less than 5.0, 8 lakes (7%) with pH values between 5.01 and 5.50, 24 lakes (22%) between pH 5.51 and 6.00 and the remaining 74 lakes (69%) with pH values exceeding 6.00 (Fig. 21). Lake pH levels may reflect the acidity of precipitation but appear to be more strongly influenced by the regional lithology. The spatial distribution of pH (Fig. 22) illustrates that the lowest pH values (5.5 and less) are located on the eastern side of the Northern Peninsula, along the south and southwest coast, and also in the northeast corner of the province. These regions, although receiving apparently different levels of deposition, are all underlain by acid sensitive geotypes (granites and gneisses). These regions are also characterized as having scant overburden and large areas of exposed bedrock. Highest values (pH 7.0 and up) were confined to lakes underlain by carbonate rich sedimentary rocks. Lakes at

intermediate pH were found in geotypes of low to moderate sensitivity (siltstones, or conglomerates/sandstone suggesting minor limestones as possible cementing agents). Agreement of pH and bedrock geology is good, and this is particularly apparent on the Northern Peninsula, where some of the most sensitive water bodies are in close proximity to lakes of unlimited buffering capacity, in many cases in the same watershed. All clear water lakes had a pH of greater than 5.50.

Lakes in sensitive terrain, receiving high acid deposition, exhibit a bimodal pH distribution (Aylmer 1976; Schofield 1976; Wright and Gjessing 1976). This bimodal distribution is consistent with the titration of a bicarbonate buffering system with strong acid (Henriksen 1980) and generally reflects two lake types; lakes with pH greater than 6.0 which have maintained intact buffering systems and lakes with pH less than 5.5 which have experienced serious depletion of buffering capacity. Lakes with pH 5.5 to 6.0 are in transition from being adequately buffered to acidified, and as this portion of the bicarbonate titration curve is steep, the transition period is short. A bimodal pH distribution therefore reflects a sensitive area that has received considerable acid deposition over an extended time frame.

The pH distribution of lakes in insular Newfoundland did not show this bimodal distribution, and a significant number of lakes (24 or 22%) were in the range of transition pH (5.5-6.0). This may reflect the fact that loadings are not sufficient, on a province-wide basis, to have titrated all the available bicarbonate buffer in the majority of the sensitive lakes. Considering only the 47 lakes in the western areas of the province receiving relatively higher sulphate deposition (excess sulphate values of 40 μ eq L^{-1} or higher), there is still no apparent bimodal distribution, although the relative contribution of lakes of "transition" range (pH 5.5 to 6.0 (8%) and 6.0 to 6.5 (8%), is diminished.

Organic acids are contributing to natural acidification of fresh waters (Henriksen and Seip 1980; Anonymous 1982), but because of the complex nature of the organic fraction it has been difficult to characterize or quanitify this contribution. Work in the Kejimikujik calibrated watershed in Nova Scotia has suggested that the organic acid concentration can be approximated from dissolved organic carbon by the following relationship; [organic acid] = 11 [dissolved organic carbon], on an equivalent basis (Kerekes 1982). Henriksen and Seip (1980) determined the organic acid concentration in Norwegian waters to be about 5.5 times the dissolved organic carbon content, while Schnitzer (1978) determined the acid concentration for a theoretical fulvic acid to be close to 20 μ eq per mgC^{-1}. Component acids may vary between regions and this would influence the relative acidity of the organic fraction. Organics are an important contributor of hydrogen ions to fresh water and, as pH is an intensity function based on hydrogen ion concentration, organics will be contributing to a decline in pH. However, in the pH range less than 5.0, organic anions can assume a significant role as a weak buffer, in the absence of bicarbonate ion.

Work is currently underway to determine the acid dissociation constants of diverse aquatic organic acids from areas across Canada. This research will establish the proportionate hydrogen ion (H^+) contribution from mineral acids

deposited through precipitation and from the dissociation of naturally occurring weak organic acids (Glass et al. 1981). This information may assist in establishing the role of organics in freshwater chemistry in insular Newfoundland, and as natural acidifying agents.

Alkalinity

Alkalinities were determined by potentiometric titration and Gran plots (field measured values) and by a two end point titrimetric method (Lab measured values). Values as determined by both methods were strongly correlated ($r = 0.97$), and total inflection point alkalinities (field values) were generally lower than two end point alkalinities, particularly with values of less than 100 μ eq L^{-1}. TIP Alkalinities were considered to be a more reliable measure (Strumm and Morgan 1981), particularly in dilute waters, and were subsequently used for bicarbonate calculation and all assessments of the alkalinity.

Alkalinity values ranged from -6.4 to 1740 μ eq L^{-1} $CaCO_3$ reflecting the wide range in sensitivities of the study lakes to potential acidification. Applying Ontario Ministry of the Environment's lake sensitivity classification (Ontario Ministry of the Environment 1981) we see that 56 lakes (52%) are classified as extremely sensitive (0-40 μ eq L^{-1}), 37 lakes (34%) are moderately sensitive (40-200 μ eq L^{-1}), 4 lakes (4%) are low in sensitivity (200-500 μ eq L^{-1}) and 4 lakes (4%) are insensitive (>500 μ eq L^{-1}) (Fig. 23). Three lakes with negative alkalinities could be classified as acidified. It is apparent that the majority of the lakes (92%) fall below the accepted standard for sensitivity (200 μ eq L^{-1}).

Based on spatial distribution of alkalinity (Fig. 13), extremely sensitive areas (<50 μ eq L^{-1}) include extensive areas on the south coast and most of the eastern region, north-central Newfoundland, and a large area on the eastern side of the Northern Peninsula. These regions are underlain by igneous geotypes resistant to weathering and poor in available carbonates, have scant overburden, and many of the watersheds are associated with extensive organic deposits. Areas of low sensitivity and of unlimited buffering capacity lie along the western margin of the province and the tip of the Northern Peninsula.

Alkalinity of freshwaters in insular Newfoundland is generally due to the carbonate-bicarbonate-carbonic acid buffering system, and all of the study lakes (pH <8.39) are expected to have buffering systems dominated by the bicarbonate ion. However, in dilute waters or waters undergoing acidification (exhaustion of bicarbonate), other minor components of a buffering regime may become important. Kramer (1976) has stated that waters in the pH range 4.0 to 6.0 may contain a number of additional buffering systems including anions of weak acids (silicic, phosphoric, hydrofloric, humics, fulvics), ammonia, or other metal (aluminum and iron) or silica oxides. Aluminum and weak organic acids may act as the most significant of potential buffers in bicarbonate poor or acidified waters (Henriksen and Seip 1980; Driscoll 1980). The buffer intensity of these two components is greatest between pH 4.0 and 5.0 (Bisogni and Driscoll 1979). Organics also play a role in the bioavailability of aluminum, iron and other metals therefore further complicating the question of

buffering ability, metal toxicity, and the acidification process in insular Newfoundland.

Lee and Brossett (1978), Glover and Webb (1979), Henriksen and Seip (1980), Wiltshire and Matchell (1981), and others have reported on the availability of potential buffers in bicarbonate poor waters, focusing on organic anions. The behaviour of organic anions varies considerably from region to region, perhaps as a consequence of varying analytic methods or as a result of differences in the components of the dissolved organic fraction. It is therefore difficult to characterize or quantify any acid-base response on the basis of quantity of dissolved organic carbon.

Kramer (1976), Cronan and Shofield (1979), and Johnson (1979) have reported on the role of aluminum in buffering acid in terrestrial and aquatic regimes. In regions receiving intense acid deposition hydrogen ion consumption in the soil is accompanied by a rapid dissolution of aluminum (ion exchange reaction). This aluminum acidity stage is a rapid process that can persist and become involved in the weathering process. The second stage of the process involves the slower chemical weathering reactions of overburden and bedrock by this aluminum acidity fraction (Johnson 1979). Henriksen (1981) suggests that in calcium poor regions the second stage of buffering may not take place to any appreciable extent resulting in acid, aluminum rich waters. The buffering potential of aluminum is related to its concentration and the speciation of the metal, but generally the metal and its complexes are believed to be operative as a buffer only in the pH range of 4.5-5.0 (Johannessen 1980). Organic complexing of aluminum can also diminish the buffering potential of the ion.

No attempt has been made to determine the component anion species contributing to alkalinity in the study lakes. Considering the high component of coloured lakes in the sample, the question of buffering potential of organic anions is important. Evaluating the Gran plots (after Lee and Brossett 1978) for ponds representating three lake types; bicarbonate rich - clear water, bicarbonate poor - clear water, and bicarbonate poor - highly coloured, there is no apparent indication of contribution of organic ions in the buffering regime over the pH range 5.0 to 3.5. Both highly coloured and clear water lakes, low in bicarbonate, demonstrated similar titration curves.

Conductivity

Specific conductance or conductivity provides a measure of the total concentration of charged ions and may be considered a reliable indicator of sensitivity to acidification. Conductivity values ranged from 11.4 to 119.0 μ S cm^{-1} (mean of 28.9). Fifty lakes (46%) had conductivities at less than 20 μ S cm^{-1} while 43 lakes (40%) had values of between 20 and 30 μ S cm^{-1}, emphasizing the dilute nature of the majority of Newfoundland lakes (Fig. 24). Lakes with a specific conductance less than 30 μ S cm^{-1} are considered critically sensitive to acid precipitation, and this would include 93 (86%) of the study lakes.

Conductivity is strongly related to certain ionic species (calcium, magnesium, chloride, sulphate, sodium) and less closely to others

(bicarbonate), depending on the specific conductivities of each ionic component. In this study conductivity was found to be strongly correlated with the sum of cations ($r = 0.99$), and the following ions; calcium ($r = 0.86$), magnesium ($r = 0.93$), sodium ($r = 0.77$), chloride ($r = 0.73$), bicarbonate ($r = 0.74$) and sulphate ($r = 0.56$).

Conductivity can often be related to the lithology of drainage basins in a heterogeneous sample of lakes, or more specifically to the solubility of minerals in the watershed. In a region of strong marine influence this relationship can be obscured. In low conductivity (dilute) waters, marine ions, particularly chloride and sodium, can dominate the influences of geochemistry, and this can be further modified by the coastal gradient in deposition of marine ions. Chloride, and to a lesser extent sodium, have high specific conductivities and contribute significantly to the conductance in dilute coastal systems. Conductivities in Newfoundland lakes were higher than continental lakes of similar salinities due to the preponderance of chloride in the region (Armstrong and Schindler 1971). Nevertheless, lakes underlain by igneous geotypes; gneisses, granites and volcanics were characterized by particularly low mean conductivities of 17.5, 21.7, and 24.0 $\mu S\ cm^{-1}$, respectively.

LAKE STATUS

To evaluate lake water chemistry and potential damage from acidification, it is important to consider that the hydrological and chemical components of a lake are dynamic and can experience wide fluctuations over time. This is particularly true of systems of intermediate acidity (pH~5.5) that are considered sensitive to potential acidification (Overrein et al. 1980). Temporal changes in water chemistry are strongly related to hydrological dynamics and can be greater than long term alterations (Harvey et al. 1981). Temporal fluctuations are controlled by a variety of physical, chemical and biological factors but seasonal variation in many water quality parameters is most strongly related to surface runoff or discharge (Hem 1970; Hutchinson 1957).

An examination of the hydrological data for guaged rivers in insular Newfoundland in 1981 (Environment Canada, Water Survey of Canada records) indicates that the months of July, August, and September were very dry, resulting in low mean monthly discharges. For 40 rivers examined, August and September were the months of lowest discharge for the year. Discharge increased in October, but examination of daily flow records indicates that low discharge was also characteristic of the first half of the month. Highest values of pH's, alkalinity and other variables associated with acidification are usually associated with periods of low runoff (Gjessing et al. 1976). As our study period corresponded to a period of very low runoff, we are essentially evaluating a "best case" scenario in relation to sensitivity to or damage from acidification.

Ratio of Bicarbonate to Sulphate

Anthropogenic inputs of acid can be partially or wholly neutralized within the hydrological or terrestrial regime associated with each water body (Harvey et al. 1979). Lakes in watersheds with limited ability to regenerate buffers and receiving continuous moderate to high atmospheric loadings of acids, will experience depletion of the available reservoir of buffers. Soil and runoff acidity will then increase, resulting in elevated acidity of receiving waters. Lakes and rivers influenced by atmospheric inputs have lost much of their bicarbonate buffering ability and sulphate, in the absence of significant inputs of chloride, becomes the dominant anion (Oden 1976).

Oden (1976) suggested the comparison of bicarbonate and sulphate concentrations (or bicarbonate to excess sulphate in regions of marine influence) be used as a preliminary indicator of acidification. A plot of lake pH versus the ratio of bicarbonate ion to excess sulphate ion (Fig. 25) suggests that in 48 lakes, excess sulphate has become dominant to bicarbonate. This is particularly true for lakes of pH 6.3 and less. The buffer intensity of a dilute bicarbonate solution is at a maximum of 6.3 and declines rapidly with declining pH. The dominance of excess sulphate in the lower pH ranges is therefore consistent with the dynamics of bicarbonate titration (Stumm and Morgan 1981) and there is certainly indication of bicarbonate replacement by sulphate in lakes of pH less than 6.30. Many of the extremely well buffered lakes (15) demonstrated bicarbonate:excess sulphate ratios in excess of 5.1 and were excluded from this figure.

Cation - Alkalinity Relationships

As lakes are subjected to large inputs of anthropogenic acids, cations are mobilized within the watershed, primarily through soil acidificiation, and sulphate ion replaces bicarbonate ion, resulting in the alteration of the normal balance between major cations (calcium and magnesium) and bicarbonate (Harvey et al. 1981). Henriksen (1979) states that since alkalinity of waters is derived primarily from the weathering of carbonates, then non-marine calcium and magnesium should be proportional to bicarbonate ion in unaffected regions. A departure from this stoichiometric relationship would be a result of bicarbonate consumption in response to mineral acid loading. This relationship has been substantiated for both affected and unaffected regions in Sweden (Aylmer 1978), Norway (Henriksen 1979) and North America (Harvey et al. 1981).

The equivalent balance between major cations and bicarbonate alkalinity, as expected for non-impacted regions, is not evident in our study lakes (Fig. 26), and most of the lakes fall below the 1:1 line indicating a deficiency in bicarbonate. Previous evidence had suggested that Newfoundland could be considered a non-impacted area (Harvey et al. 1981) but most study lakes are demonstrating an alkalinity deficiency in the order of 25 to 50 μ eq L^{-1} (at the time of sampling). The distance below the equivalence line has been presented as a measure of the degree of acidification as shown by a comparison of lakes unaffected by acid deposition to those undergoing moderate to high acid loadings (Harvey et al. 1981). A comparison of the cation-alkalinity relationships between regions in eastern Canada (unpublished DFO data as provided by J. Cooley pers. comm.) indicates that lakes in insular

Newfoundland appear to be demonstrating the smallest depletion of buffering ability and it is suggested that this a consequence of "apparent" lower loadings. The extreme sensitivity insular Newfoundland lakes must be emphasized as a further decline in alkalinity in the order of 25 μ eq L^{-1} would push many of the study lakes (27 of 44) with non-marine calcium and magnesium concentrations of less than 75 μ eq L^{-1} towards acidification.

It has been postulated that calcium and magnesium levels in freshwater may be increased due to increased rates of weathering by strong mineral acids, (Aylmer et al. 1978). If most of this acid input is proportional to excess sulphate, then a good relationship should exist between excess sulphate and the sum of calcium and magnesium minus bicarbonate on an equivalent basis. Several researchers have reported an increased cation export in watersheds receiving high acid loadings (as summarized in Overrein et al. 1980; Harvey et al. 1981). This relationship also provides a measure of the calcium and magnesium derived from mineral acid weathering as opposed to carbonic acid weathering, although implicit in this evaluation is that there is not necessarily a cause-effect relationship. A plot of this stoichiometric relationship for the study lakes (Fig. 27) reveals that, for the most part, our lakes are widely scattered about the equivalence line, and there is no apparent strong agreement. The fact that the study lakes do not demonstrate good agreement with this relationship, while lakes in high deposition areas do (Harvey et al. 1981), suggests that loadings in insular Newfoundland may not be high enough for mineral acid weathering of major cations to have become significant.

pH - Calcium Relationships

Henriksen (1979) has developed a simplistic approach to identifying acidification based on the relationship between pH and non-marine calcium. The model is based on the premise that pre-acidification alkalinity and pH can be estimated from current calcium values; that is the process of acidification reduces alkalinity without causing a significant change in calcium ion levels.

He has stated that the ratio of calcium to magnesium was constant for his study lakes, and therefore calcium alone could be used to represent cations and the associated equivalence of alkalinity. The calcium/magnesium ratio in our study lakes was similar in sensitive geotypes, ranging from 1.2-2.7 to one (average near 2:1). Calcium was much more dominant in non-sensitive geotypes suggesting the ready availability of calcium carbonates. The ratio of these two cations was relatively constant for sensitive lakes and therefore meets the criteria to use calcium in the model.

Henriksen drew an empirical curve to separate acidified and non-acidified lakes in Norway. Lakes falling above the line were receiving strongly acid precipitation ($<$pH 4.6) and were demonstrating strong evidence of acidification, while lakes below the line were receiving rainfall of pH 4.6 or greater and were showing little or no signs of acidification. There was also north-south geographical separation of lakes. Henriksen's relationship has proved valid for lakes in Norway, Sweden, the United States, and Canada (Harvey et al. 1981) and has been presented as a first order approach in the identification of acidified or acidifying lakes. Henriksen uses the term "acidification" to be synonomous with loss of alkalinity, therefore enabling

the model to identify lakes with apparently safe pH's that may have been affected by significant loss of buffering ability.

The relationship between pH and calcium for our study lakes is plotted with Henriksen's empirical curve in Figure 28. Ten lakes fall in the "acidified" portion of the diagram with the remaining lakes (84) in the "non-acidified" region. The ten lakes in the acidified portion were rather dispersed geographically, with three lakes in the southern half of the Northern Peninsula (#'s 12, 14, 15), three in the southwest region (#'s 203, 205, 207), two in the northeast corner (#'s 102, 105) and two lakes in central Newfoundland (#'s 72, 74). All lakes were characterized by high colour (55-225) indicating relatively high levels of natural organic acidity. Excess sulphate levels for the ten lakes were above the mean for all lakes, ranging from 38-91 μ eg L^{-1}. Using Henriksen's depositional criteria and considering the "apparent" loadings in insular Newfoundland (pH 4.5-4.9), it is expected that most lakes would fall in the non-acidified portion of the figure (remembering that higher precipitation in insular Newfoundland would result in higher hydrogen ion and sulphate loadings).

High excess sulphate in two lakes (#'s 72, 74) has been related to potential geological sources, suggesting natural acidification. The high colour in five lakes (#'s 102, 105, 12, 14, 15) suggests a possible role for weak organic acids in reducing pH. Henriksen's model does not apply to lakes receiving unusual input of strong acids of natural origin, such as organics or oxidation of mineral sulphur. The other three lakes (#'s 203, 205, 207) with high excess sulphate and low colour values appear to indicate mineral acidification.

The role of organic acids in the pH balance in these lakes is important. Studies in Nova Scotia (Underwood and Josselyn 1980; Wiltshire and Matchell 1981) and Scandanavia (Glover and Webb 1979; Henriksen and Seip 1980) has suggested that weak organic acids do contribute hydrogen ions and lower the pH. Therefore the pH - calcium relationship, in waters of high organic content, will demonstrate the effects of acidification by both strong mineral acids and weaker organic acids. On the other hand, the relationship between major cations and alkalinity (Fig. 26) should demonstrate acidification by strong mineral acids only. Attempts to characterize or quantify organic contribution to acidification have been highly variable, due to methodological considerations and regional differences in component acids, and therefore do not lend themselves to universal applicability (Henriksen and Seip 1980; Wiltshire and Matchell 1981).

Henriksen's Nomograph

Henriksen (1980) has developed another model or "predictor" nomograph to look at the various stages of acidification, considering the process to be continuous. He considers the process of acidification to be analogous to the titration of a bicarbonate buffering system (geochemical origin) with strong mineral acids (atmospheric origin), more specifically with sulphuric acid. The model is based on equivalency between major cations (calcium and magnesium) or calcium alone in relation to bicarbonate in non-acidified waters, and the use of present cationic concentrations to predict original alkalinity.

The sum of non-marine calcium and magnesium is plotted against non-marine sulphate such that the ordinate represents geological inputs, and the abcissa represents anthropogenic inputs. Using empirically derived relationships, the nomograph is divided into three sections, corresponding to three distinct segments in the titration of a bicarbonate buffered system. The first stage, "Bicarbonate Lakes", is characterized by small decreases in alkalinity and maintenance of the bicarbonate buffered system. The second stage, "Transition Lakes", is characterized by the loss of the bicarbonate buffering system, severe fluctuations in pH, and episodic effects on biota. The final stage, "Acidified Lakes", is characterized by chronically low pH's, elevated levels of trace metals, and severe perturbation of resident biota (Henriksen 1980). It is generally thought that once lakes have reached this final stage, the process is irreversible, or can only be reversed over a long period of unstressed, geological weathering (Overrein et al. 1980).

A plot of the study lakes on Henriksen's Nomograph (Fig. 29) shows that ten lakes fall within the "Transition Lakes" zone with all other lakes in "Bicarbonate Lakes" region. No lakes fell in the "Acidified Lakes" region of the nomograph. The nomograph successfully predicted the pH of 8 of 10 of the lakes in the transition region. Examining the transition lakes on an individual basis, three lakes (#'s 68, 72, 254) can immediately be excluded due to inputs of sulphate of geological origin. Two of these lakes (#'s 68, 254) had relatively high pH's (5.72, 5.99) and high alkalinities (15.0-22.0 μ eq L^{-1}) and would not be expected to fall into the "transition lakes" category. The third lake (#72), in addition to apparent input of geological sulphate, was highly coloured (200) suggesting a significant natural acid contribution resulting in low pH (4.93) and alkalinity (1.0 μ eq L^{-1}). Excess cations for this lake also suggest an alkalinity deficiency in the order of 85 μ eq L^{-1}, which is high, considering the loadings in neighbouring lakes to be in the order of 30-40 μ eq L^{-1} of sulphate.

The remaining seven lakes (#'s 15, 19, 23, 203, 204, 205, 207) were confined to two distinct geographical regions, four lakes in the western half of the south coast and three lakes in the southern half of the Northern Peninsula. These lakes were all small (mean of 66 ha) with small WA:LA ratios (mean of 7.3:1). Annual precipitation and runoff in these areas is high and the south coast is a region of suspected high deposition. These dilute lakes (excess cations of less than 50 μ eq L^{-1}) had relatively low levels of organic acidity (colour of 10 to 65, mean of 26) with excess sulphate dominant over bicarbonate. It would appear that natural acidity may not be as significant as mineral acidity of anthropogenic origin in these lakes.

A comparison of lakes in the transition zone of the nomograph (Fig. 29) with lakes in the "acidified" region of the indicator diagram (Fig. 28), would tend to support the following conclusions. Indications of acidification is strongly related to mineral acid loadings (sulphate) in five lakes (#'s 19, 23, 203, 205, 207). In six lakes (#'s 12, 14, 15, 201, 204, 230) mineral acidification is probably being supplemented by considerable input of organic acidity. High levels of organic acidity and/or natural sources of sulphate are heavily implicated in the acid-base balance of the other six lakes (#'s 68, 72, 74, 102, 105, 254)

The nomograph may also be used in a predictive capacity, using the precipitation pH scale on the abcissa. This precipitation scale has only general applicability (owing to regional differences in the ratio of wet to dry deposition, relative sulphuric or nitric acid component in precipitation, total amount of precipitation, evapotranspiration rates, etc.) but it allows for examination of a scenario of increased deposition. There is good agreement between lake excess sulphate and the precipitaiton pH range for the island (pH 4.5 to 4.9). To examine the implications of increased deposition, a dotted line was drawn at pH 4.4, representing a 21% increase in acidity over the lowest annual pH rainfall in insular Newfoundland (pH 4.5). Under this scenario, all lakes with a sum of excess calcium and magnesium less than 50 μ eq L^{-1} would become acidified, implicating 34 of the 109 study lakes (31%). If precipitation pH declined to present levels in southern Ontario (pH 4.0 to 4.2), it is apparent the effects on lakes in insular Newfoundland would be severe.

There are two major limitations in applying and interpreting Henriksen's Indicator Diagram and Nomograph. Firstly, a basic premise of both models is that calcium and magnesium is proportional to alkalinity under conditions of carbonic acid weathering, and these two ions remain conservative under deposition of mineral acids, therefore enabling one to predict pre-acidification alkalinities based on cation content. It has been demonstrated that calcium and magnesium export is increased under conditions of strong mineral acid deposition (Glass et al. 1981). Therefore the application of these models would tend to overestimate pre-acidification alkalinity and hence the amount of acidification. This question is currently under study and more time series information is required to fully resolve the issue. A second concern is that weak acids, particularly organics, may disturb the basic cation/alkalinity/pH relationship making it difficult to isolate the roles of mineral acids and organic acids in the acidification process. Henriksen (1981) points out that lakes with high concentrations of organic acids do not meet several of the assumptions implicit in developing his relationships. In addition, ionic calcium and magnesium may be overestimated in coloured lakes as organically bound cations would be measured.

The applicability of Henriksen's nomograph to North American locales is an important question. Relationships between cations and lake sulphate may vary between regions due to differences in geochemistry. Further, the empirical relationship between lake sulphate and atmospheric sulphate must be established for each geographical area. Therefore, for accurate predictions, it would be appropriate to develop regression relationships and predator nomographs that are region-specific.

TRACE METALS IN LAKE WATER

A concern in lake acidification is the increased leaching of toxic metals, or increased availability of toxic species of metals, and the associated implications for biota. Elevated levels of trace metals including aluminum, manganese, zinc, cadmium, lead, copper and nickel have documented in Europe and North America (Glass et al. 1981); Haines 1981; and Harvey et al. 1981). Metals such as zinc and lead in southern Norway lakes (Henriksen and Wright 1978) and nickel and copper in Sudbury lakes (Beamish 1976) are apparent

through direct atmosphereic deposition (wet and dry). Another mechanism for elevated levels of trace metals in lakes is the mobilization and transport from the surrounding terrestrial watershed or lake sediments. The principal sources for aqueous aluminum and manganese is the dissolution and leaching of the metal from surrounding soils (Harvey et al. 1981). These two metals demonstrate an increasing solubility with declining pH (over the range pH 5.0 to 7.0), so as soil acidity is increased through atmospheric deposition, aluminum and manganese are released and transported to lakes and streams (Cronan and Schofield 1979).

Cadmium, lead, copper, zinc, and nickel were in very low concentrations, largely at or below the limits of detection. Cadmium levels ranged from less than 1 to 2 $\mu g\ L^{-1}$, copper less than 2 to 3 $\mu g\ L^{-1}$, while lead, zinc and nickel did not exceed detection limits. There is no evidence for atmospheric deposition or increased mobilization of these metals in relation to acid deposition.

Aluminum, manganese, and iron were found in detectable quantities across the data set. Total iron values ranged from 7 to 1197 $\mu g\ L^{-1}$ (mean 165). Most values in excess of 400 $\mu g\ L^{-1}$ were confined to geographical areas with anomolously high excess sulphate values (Fig. 17 and 18). As mentioned previously, these are thought to be areas that contain gypsum and/or pyrite deposits and these two minerals are high in both sulphur and iron. Iron values were not found to be correlated with lake pH.

Aluminum and manganese were significantly correlated with lake pH with regression coefficients of 0.43 ($P < 0.001$) and 0.33 ($P < 0.005$) respectively. This relationship is only apparent in brown water lakes (colour >15) (Fig. 30 and 31). Lake aluminum and lake manganese were also correlated to dissolved organic carbon; $r = 0.81$ and $r = 0.49$, respectively. Clear water lakes are generally associated with low values of aluminum (90 $\mu g\ L^{-1}$ and less) and manganese (10 $\mu g\ L^{-1}$ and less), and may represent "background" levels for these two metals. Organic anions appear to be playing a role in the dissolution and mobilization of these metals. Johnson (1979) has reported that the presence of organic ligands can greatly enhance aluminum solubility by forming organic-aluminum complexes which are transported through the soil profile and into lakes and streams. All study lakes demonstrating high aluminum values ($>200\ \mu g\ L^{-1}$) were associated with high colour values (80-225). Dickson (1978) for lakes in Sweden and Wiltshire and Matchell (1981) for lakes in Nova Scotia and New Brunswick have reported similar relationships between organic carbon (or colour) and total aluminum values. Stumm and Morgan (1981) have indicated there is a strong tendency for humics and fulvics to form complexes with metal ions, and these complexes can be the dominant species of the available metal. While aluminum availability in soils is generally unlimited, manganese in extremely acid environments may ultimately be limited by the availability of manganese within the watershed.

Generally total aluminum and total manganese values for Newfoundland lakes were lower than those reported for lakes and streams in acidified regions of North America and Scandanavia (Overrein et al. 1980; Harvey et al. 1981; and Haines 1981). Total aluminum values for Newfoundland lakes ranged from 0 to 430 $\mu g\ L^{-1}$ (mean 112) while total manganese ranged from 0 to 52 $\mu g\ L^{-1}$ (mean

13). Lakes along the west coast of Sweden had aluminum values between 200 to 650 $\mu g\ L^{-1}$ (Almer et al. 1978) while lakes in high deposition areas in southern Norway demonstrated values between 40 to 600 $\mu g\ L^{-1}$ (Wright et al. 1976). Lakes with pH <5.0 in Finland had aluminum levels from 180-470 $\mu g\ L^{-1}$ (Anonymous 1982). In North America, lakes in the Adirondack Mountains of New York had a mean aluminum level of 286 $\mu g\ L^{-1}$ (Schofield and Trojnar 1980) while some acid lakes in Ontario had values ranging from 80 to 700 $\mu g\ L^{-1}$ (Spry et al. 1981). Lakes of intermediate pH (5.4 to 6.0) in Norway and Ontario had aluminum values of 50 to 90 $\mu g\ L^{-1}$ (Harvey et al. 1981) or and 80-100 $\mu g\ L^{-1}$ in Finland (Anonymous 1982). These values are similar to levels in many of Newfoundland's clear water lakes. Manganese values in lakes in acidified regions were considerably higher than those in Newfoundland lakes, ranging from 300-400 $\mu g\ L^{-1}$ in Sweden (Dickson 1975) and 100-350 $\mu g\ L^{-1}$ in Ontario (Scheider et al. 1979).

Levels of aluminum and manganese alone, or in relation to pH toxicity, may be the primary mechanism limiting the survival of fish and other biota (Haines 1981). Similarly, pH tolerance can be affected by the availability of toxic forms of aqueous aluminum. In laboratory studies brook trout have demonstrated toxic response to aluminum concentrations above 200 $\mu g\ L^{-1}$ over the pH range 4.4 to 5.9, while sublethal effects were demonstrated at aluminum concentrations of 100-300 $\mu g\ L^{-1}$ (Cronan and Schofield 1979). Aluminum speciation and toxicity is primarily governed by pH and the availability of potential ligands (flouride and organic complexes), with the hydroxyl or inorganic forms most toxic and the organically complexed forms relatively non-toxic (Driscoll et al. 1980). They further report that aluminum-organic complexes were the dominant monomeric form available in the surface waters of the Adirondack region and this component increased linearly with organic carbon content. Aluminum values in our study, and indeed most values reported in the literature, are for total aluminum, and not for the component species of the metal. However, aluminum values in excess of 90 $\mu g\ L^{-1}$ were associated with brown water in Newfoundland lakes and values in excess of 200 $\mu g\ L^{-1}$ associated with the highly coloured lakes. It is probable that much of the available aluminum is organically complexed and non-toxic.

The dissolution and transport of metals to surface waters in response to mineral acidification can be largely an episodic phenomenon (Harvey et al. 1981). High levels of aluminum can be found in association with pH depression in surface waters during periods of high runoff (Gjessing et al. 1976). The episodic nature of aluminum availability was not investigated in this study.

FISH RESOURCES

The loss of fish populations in response to anthropogenic acidification was first reported in Scandinavia (Jensen and Snevik 1972). In Norway, with some 200,000 lakes, approximately 20% of these lakes have already been adversely affected by acidification and this number continues to increase (Lievstad 1976). Sweden, with about 90,000 lakes, has also experienced serious acidification damage to about 18,000 lakes with about 9,000 lakes showing serious damage to fish stocks (Bengsten et al. 1980).

In North America, several regions have reported acidification damage to freshwaters and resident fish. In Ontario, lakes from several regions have demonstrated acidification damage to fish communities (Beamish and Harvey 1972; Somers 1980; Harvey et al. 1981). In Ontario, it has been estimated that 2000 lakes have lost fish populations due to acidification while an additional 48,000 are threatened over the next 20 years (Harvey et al. 1981). Minns (1981) has estimated that some 1200 lakes in Ontario are currently acidified and an additional 3442 lakes are similarly threatened. In Quebec, reduced angling success in Laurentide Park has been related to acidification damage to fish stocks, and it is likely there is further unreported damage in other areas (Richard 1982). In Nova Scotia, several rivers can no longer support natural reproduction of Atlantic salmon, and other rivers are moving towards this situation (Watt et al. 1983). In the United States, affected regions in the northeast include the Adirondack Mountains area in New York where 43% of 214 surveyed ponds are devoid of fish life (Schofield 1976).

It is initially important to outline constraints in interpretation of the results of the gillnet survey of study lakes in insular Newfoundland, in relation to potential impacts due to acidification. Firstly, it is difficult to reliably determine presence/absence of fish in lakes from a single gillnet set over a period of one or two days. The presence of fish is much easier to demonstrate than absence, and a much greater sampling effort, using a variety of sampling methods would be required to reliably determine if a pond is "fishless". Secondly, the survey period (August 20 to October 18) overlapped with the prespawning or spawning period of resident salmonids. As all resident salmonids are predominantly stream spawners (Scott and Crossman 1964), it is probable fish were either in prespawning concentrations in an unsampled area in the lake or may have moved into streams for spawning. Of a total of 27 ponds in which no fish were captured, four (15%) were sampled in the first half of the survey (before September 15) while 23 (85%) were sampled during the second half (September 16 to October 18). The highest proportion of lakes in which no fish were captured were encountered in the month of October suggesting strong seasonal influences on fish capture.

In relation to any assessment of abundance, in this case catch per unit of effort (CPUE), the same considerations apply. In addition to fish availability in relation to spawning activities, there is also a progressive decline in water temperatures over the study period. Reduced water temperatures and spawning activities should result in a decline in foraging activity. As gillnetting is a passive sampling technique, reduced activity would make fish less susceptable to capture. For these two reasons it is difficult to compare fish abundance between ponds sampled in the summer and fall. The minimum mesh size employed in the survey was 3.8 cm (stretched measure) which did not permit sampling of the younger age classes (0^+, 1^+, and to a lesser extent 2^+) of resident salmonids or potential forage species. For this reason, and also because of the small sample size obtained from many ponds, it is of little value to assess age class structure, and in particular, possible recruitment failure (missing age classes) as early indicators of potential acidification damage as suggested by Overrein et al. (1980) and Harvey et al. (1981).

A total of 1216 fish were netted from 81 of 109 lakes (74%). Brook trout (Salvelinus fontinalis) were the dominant species (numerically), 759 (62%), followed by landlocked Atlantic salmon or ouananiche (Salmo salar), 404 fish (33%), 51 (4%) anadromous Atlantic salmon (Salmo salar) and two brown trout (Salmo trutta). Both brown trout were anadromous and it is likely a portion of the brook trout catch were also sea run.

Brook trout are well distributed across the island, and were netted from lakes in all geographical regions, in lakes from the five major geological types, and in 69 of the 81 lakes (85%) in which fish were captured. Trout were either the dominant species or equally abundant as ouananiche in all regions but the Avalon Peninsula, and were particularly dominant on the Northern Peninsula and in the western region. This is not surprising as the lakes sampled are preferred habitat for brook trout. Kelso and Minns (1981) suggest that brook trout will be the species most affected by continuing acidification as they are occupying the most sensitive habitats (headwater lakes and streams).

Ouananiche were also distributed across the island, with the notable exception of the Northern Peninsula and the western region, where they were found in only one of 30 lakes. Ouananiche were netted from 32 lakes (40%) and were found in about equal numbers with brook trout in the eastern region and were the dominant species (by number) in the southern and central regions. It appears that the Long Range Mountains have played an important role in the zoogeographical distribution of ouananiche. Ouananiche were not taken from the three ponds on the Avalon Peninsula but are known to be common on the Avalon Peninsula (Wiseman 1973; Whelan and Wiseman 1974).

Anadromous Atlantic salmon were captured in 11 (14%) lakes representing all six geographical regions. This low rate of capture is not surprising as most study lakes were located high in their respective drainage systems, and in many instances were likely isolated from the sea by natural or man-made barriers.

Brown trout were taken from one pond on the Avalon Peninsula and both fish captured were large, sea-run individuals. This species was introduced to the island in the lake 1800's and early 1900's and is mainly restricted to the Avalon Peninsula (Andrews 1964).

Two other salmonids occurring in the freshwaters of insular Newfoundland, Arctic char (Salveninus alpinus) and rainbow trout (Salmo gairdeneri), were not captured during the survey. Other freshwater inhabitants of insular Newfoundland that were not captured during this study included three-spine stickleback (Gasterosteus aculeatus), four-spine stickleback (Apeltes quadracus), nine-spine stickleback (Pungitius pungitius), the American eel (Anguilla rostata), and rainbow smelt (Osmerus mordax).

The fish communities or species assemblages across the survey lakes reflect the low species diversity of insular Newfoundland fish fauna. Three of ten freshwater or anadromous species occurring in insular Newfoundland were captured and brook trout and landlocked Atlantic salmon dominate the sample. Of 24 possible species assemblages (considering ouananiche and anadromous

salmon separately), only seven are represented in the sample (8 of 25 including lakes with no fish). Comparatively, Minns (1981) determined a possible 21 assemblanges for Ontario lakes, considering only game species and grouping warmwater fish as families. This serves to emphasize the geoghraphic differences in species diversity, and the relative simplicity fish communities in insular Newfoundland.

Fish species assemblages for the 81 study lakes, in order of dominance, were as follows: brook trout only - 43 lakes, brook trout and ouananiche - 24 lakes, ouananiche only - five lakes, brook trout and anadromous Atlantic salmon - four lakes, anadromous salmon and ouananiche - two lakes, anadromous salmon only - two lakes, and brown trout/brook trout/anadromous salmon - one lake. Lakes with only one species were most abundant (50 lakes or 62%) while two species were found in 30 lakes (37%) and three species were present in only one lake (1%).

Minns (1981) reported brook trout only lakes to be the dominant fish community in Ontario lakes, despite the greater diversity in fish species in that province. He also noted brook trout lakes were generally the smaller (10-100 hectares), more isolated (i.e. headwater) lakes. He demonstrated a relationship between lake size and community complexity with a greater species diversity associated with larger lakes. The distribution of species assemblages is primarily governed by geographic distribution, and is influenced as well by climatic and limnological factors.

Brook trout ranged in length from 134 to 501 mm, 26 to 1634 g in weight and ages two to seven. Very few fish less than 160 mm were captured and the majority of the fish ranged between 160 and 360 mm in length (92% of the total catch), representing age groups 2+ to 5+. Larger (>360 mm) and older (ages 6+ and 7+) brook trout were evident in ponds from all regions, excepting the Avalon Peninsula, and fish greater than 360 mm, were particularly prevalent in the well buffered (higher productivity) ponds on the Northern Peninsula. Fish of this size comprised 13% of the total trout catch for this region. The male:female ratio for the total sample is 1.27 with males particularly dominant on the Northern Peninsula (male:female ratio 1.70). A total of 81% of the trout captured were mature (76% of the males and 87% of the females).

Ouananiche ranged from 135 to 539 mm in length, 27 to 1360 g in weight, and ages two to eight. Ouananiche were generally larger than brook trout with 80% of the total catch in the 160-360 mm range and 18% larger than of 360 mm. Large fish, in excess of 410 mm, were represented in the central and eastern regions but not in the southern region. Again there was a slight male dominance in the total sample (male:female ratio of 1.33), with this dominance most evident in the central region (male:female ratio 1.78). Only 55% of the ouananiche were mature. Ouananiche in eastern North America have demonstrated alternate year spawning (Harvey and Warner 1970; Leggett and Power 1969) which may be reflected in the proportion of mature ouananiche.

Anadromous Atlantic salmon were mostly grilse (1SW) and included three juveniles. Adult salmon ranged from 412 to 600 mm in length and 875 to 2268 g in weight.

A summary of sex and maturity data for all fish and for length, weight and age, by region is contained in Tables 3 and 4, respectively. Catch per unit effort (CPUE) estimates were calculated for all lakes in which fish were captured, and are presented in Table 5 (brook trout) and Table 6 (ouananiche). Estimates ranged from 0.3 to 34.8 fish per day (0.3 to 31.3 for brook trout only, and from 0.9 to 25.7 for ouananiche only) or from 0.03 to 16.95 kg per day (0.08 to 13.1 for brook trout, and from 0.04 to 8.71 for ouananiche). Effort ranged from 12 to 107 hours, with most sets between 24 to 48 hours. Estimates of CPUE (for all fish by numbers and weight) were regressed against lake morphometry, chemical status and productivity parameters. No parameters were significant in determining the variance in CPUE ($P > 0.01$) for all species combined.

Estimates of catch per unit effort (for brook trout and ouananiche separately) were then regressed against parameters representing geography (region), bedrock geology, chemical status (pH) and lake morphometry (surface area). Brook trout abundance increased with increasing pH and declined with increasing lake surface area. Potential fish productivion is governed by morphometric and chemical parameters as expressed by the morphoedaphic index (Ryder 1965). The morphoedaphic index (MEI) is calculated by dividing total dissolved solids (TDS) by mean depth ($\bar{z}$). In this study, TDS and lake pH were positively correlated ($r = 0.57$) indicating expected increased trout productivity with increased pH. Mean depth was not determined for the majority of the study lakes, but depth is strongly related to surface area for lakes in areas of similar topography (Hutchinson 1957). The apparent decline in trout abundance with increased lake surface area is also consistent with considerations of lake morphometry in Ryder's relationship.

A relationship has been demonstrated between community structure or presence/absence of one or more species with lake pH (Overrein et al. 1980; Harvey et al. 1981). Kelso et al. (1980) reported an increase in fishless lakes with decreasing pH in lakes near Sault Ste. Marie, Ontario. Considering lakes in insular Newfoundland, a similar increase in the incidence of "apparently" fishless lakes is apparent with declining pH class (Fig. 32). In particular one lake with pH of less than 5.0 was "fishless", while five lakes (63%) with pH 5.0 to 5.5 were "fishless". The proportion of lakes in each pH class in which no fish were captured then declines with increasing pH until all lakes above pH 7.5 contained fish. Considering the two most abundant species, brook trout were found in only two of nine lakes below pH 5.5 while ouananiche were found in one of nine lakes below pH 5.5. Ouananiche were taken from only four of 35 lakes with pH less than 6.0. Brook trout were present in lakes with pH 5.00 to 8.39 while ouananiche were present in lakes with pH 5.45 to 7.68.

Considering the sampling constraints previously mentioned with respect to the reliability of presence/absence data, it is important that this apparent relationship between lake pH and fish absence not be given undue consideration, without further substantiation. Brook trout, as evidenced by their presence in an extremely highly coloured acid lakes on the Northern Peninsula (pH 4.4-4.7), are presently surviving in low pH waters in insular Newfoundland. Minns (1981) decided not to include naturally acid, dystrophic lakes in his assessment of acidification in relation to inland waters, as the Ontario Ministry of Natural Resources considered this lake type to have very limited fisheries potential.

Minn's criteria (pH < 6.0, brown coloured, low secchi disc depth, dilute) suggests that eight of the study lakes could be considered dystrophic, and five of these were apparently fishless. However it is apparent from this study that this lake type is abundant in insular Newfoundland and is a significant contributor to overall trout production.

Fishless lakes were represented in all geographical regions, the five major geological types, and in lakes of pH up to pH 7.50. However, 74% of these "fishless" lakes were confined to two geographical regions; 11 of 24 lakes in the southern region and nine of 23 lakes on the Northern Peninsula. Lakes in these two regions are among the most sensitive and six of these lakes are showing some evidence of acidification. However, further sampling effort is required to demonstrate any link between lake status (as indicated by pH) and fish presence/absence. In addition, any pH-fish presence/absence relationship is not necessarily linked to a cause-effect relationship between atmospheric deposition and lake chemistry.

Fish presence/absence was assessed in relation to lake colour and no clear relationship was apparent. Naturally acidic dystrophic lakes are recognized to have limited potential for fish production and 33% of lakes of colour >100, and 28% of lakes with colour values between 50 and 100 were "fishless". A high proportion of fishless lakes, however, were clearwater, suggesting a possible influence of water colour and clarity on gill net efficiency.

CONTAMINANT BODY BURDEN IN FISH

Tissue from 965 fish, representing all four species, were analyzed for the following trace metals: mercury, aluminum, manganese, cadmium, arsenic, selenium, nickel, and zinc, and as well as for total lipid content (TLC). A total of 509 brook trout (67% of the total), 404 ouananiche (100%), 47 anadromous Atlantic salmon (92%), and two brown trout (100%) were analyzed. Results for individual analysis of all parameters is housed on computer tape at the Northwest Atlantic Fisheries Centre, St. John's, Newfoundland.

Mercury levels in fish tissue ranged from 0.02 to 1.3 ppm. A total of 72 fish contained levels in excess of the National Health and Welfare accepted minimum standard of 0.5 ppm in fish tissue intended for human consumption. Fifteen brook trout (3%), six anadromous Atlantic salmon (12%) and one brown trout (50%) contained Hg levels in excess of 0.5 ppm. Fish with these Hg levels largely represented widely separated, isolated occurrences. Fifty ouananiche (12%) possessed mercury levels in excess of 0.5 ppm level and six lakes contained several individuals of mercury content in this range. These six lakes were widely separated geographically, and had lake pH's ranging from 5.70 to 7.60. It is suggested there may be a geological source for mercury in these watersheds as has been described for certain Labrador lakes (Bruce and Spencer 1979).

Fish from acidified lakes may contain elevated concentrations of mercury and other metals and this phenomenon is commonly related to a reduction in pH and alkalinity (Haines 1981). The mechanisms for the increased availability of mercury is unclear but is likely related to increased mobilization from the watershed and increased methylation of inorganic mercury (the form most readily

uptaken by fish) in low pH water; in particular over the pH range 5.0 to 7.0 (Wood 1980). Tomlinson et al. (1980) believe that low pH leads to higher mercury in fish due to increased retention of mercury in the water column under acid conditions (resulting in increased exposure to fish) and the concentration of metals in fish tissue due to declining biomass and growth rates in response to pH decline.

Aluminum levels in fish ranged from 0 to 4.6 ppm and manganese levels ranged from 0 to 3.9 ppm. These two metals in lake water were related to declining pH and it was suggested that levels of these two metals, in excess of background concentrations, would be organically complexed and unavailable for uptake by fish. Aluminum and manganese in fish were regressed against parameters indicative of acidification (lake pH, alkalinity, water colour, total lake aluminum and total lake manganese), and no significant relationships ($P > 0.01$) were found for all fish and all species combined. Concern in relation to these two metals and the acidification phenomenon is more with respect to toxicological implications than for increased uptake.

Selenium levels ranged from 0.008 to 1.5 ppm but for the most part were less than 0.1 ppm. Zinc values ranged from 0.635 to 25.0 ppm. The other three metals analyzed for were found from very low to undetectable quantities in most specimens. Cadmium levels ranged from less than 5 to 101 ppb, arsenic levels from less than 0.3 to 360 ppb and nickel levels from less than 50 to 2,500 ppb.

For individual lakes with a sample size of 20 or more fish of one species, levels of metals in fish tissue were regressed against body size (length and weight) and age, resulting in no significant relationships ($P>0.01$). There is therefore no evidence for bioaccumulation of metals in fish tissue in the lakes tested.

In order to compare contaminant body burden of brook trout and ouananiche (separately) in all lakes combined, fish from all lakes were grouped by length increment classes of 25 mm or greater (from 150 to 450 mm) and levels of mercury, aluminum, and manganese in fish tissue were regressed against lake pH (Table 7). The resulting relationships indicate there is some evidence for pH control of mercury uptake in fish when fish of similar size are compared across the data set. Low pH favors increased methylation of inorganic mercury (the form most readily uptaken by fish) and increased mobilization of the metal from the watershed and sediments (National Research Council of Canada 1979). The complexity of intervening factors including geological availability of mercury, trophic level of fish (piscivorous vs. insectivorous), presence of complexing agents (soluble and particulate organic matter), and others makes any additional interpretation of body burden and lake chemistry highly tenuous. Aluminum in fish tissue was significantly related to pH in one length class for brook trout and in three length classes for ouananiche. Manganese in fish tissue was related to pH in two length classes in brook trout.

ESTIMATE OF FISHERIES POTENTIAL AT RISK

Two geographical areas were determined to be of primary concern with respect to potential acidification. An area of 14,700,000 ha on the southwest coast of the island characterized by hilly topography, igneous bedrock, shallow soil cover and extensive rock/soil barrens is considered the area most threatened. An area of 946,000 ha on the eastern side of the Northern Peninsula characterized by mountainous relief, igneous bedrock, rapid runoff and drainage, and extensive rock/soil barrens is also considered critically sensitive. The proportion of standing waters in the highly sensitive south coast region has been estimated to be 13% (195,000 ha) by Northlands Associates (1982) or 10.8% (158,000 ha) by Whelan and Wiseman (1975). In the critically sensitive portion of the Northern Peninsula, the component of standing water has been estimated to be 9% and 81,000 ha (Northlands Associates 1982) or 10.6% and 100,000 ha (Whelan and Wiseman 1975).

Whelan and Wiseman (1977) have determined to average annual potential yield for Avalon Peninsula lakes to be 3.65 kg/ha/yr. Applying this average yield figure to the estimates of standing water in areas at risk, potential fish production of some 712,000 kg/hr on the southwest coast and 296,000 kg/yr on the Northern Peninsula is threatened. Productive trout water on the island has been estimated to be approximately 34,500 km^2 with the potential to produce 12.6×10^6 kg of fish per year (W. Bruce, pers. comm.). Therefore, 1,000,000 kg/yr, or about 8% of the island's potential fish production in standing waters is associated with the identified high risk areas.

It must be remembered that potential fish yield be apportioned for resident salmonid species. On the Northern Peninsula most of the yield would be associated with brook trout production as ouananiche are absent and arctic char are likely a minor component of resident populations. For lakes on the southwest coast, ouananiche were found in greater proportion than brook trout (a ratio of 53:47 by weight, this study) and the yield must be apportioned accordingly.

Anadromous Atlantic salmon inhabit river systems in the two areas of concern and they must also be considered at risk. The productive habitat and the salmon production associated with rivers in the critically sensitive regions have previously been quantified (Atlantic Salmon Task Force 1978) and is summarized in Table 8. On the Northern Peninsula salmon rivers with 57,400 units (100 m^2) of productive rearing habitat, with the potential to produce 13,600 grilse and large salmon annually, are associated with the sensitive region. On the south coast, salmon rivers containing 106,900 units of rearing habitat with the potential to produce 60,300 salmon annually are at risk. The total annual production potential of salmon for the island has been estimated to be 591,700 fish. Therefore an annual production potential of 73,900 fish or 12% of the total for the island are associated with the geographical regions considered at risk.

CONCLUSIONS

This survey of headwater lakes in insular Newfoundland shows there is presently no widespread acidification problem in insular Newfoundland, However, lakes in many regions have been demonstrated to be among the most sensitive in eastern North America, on the basis of terrestrial and chemical variables. In addition, lakes in two particular regions of the island are demonstrating deterioration of chemical status in relation to mineral acidification. Lakes in insular Newfoundland do not appear to be as affected as those in other regions of eastern Canada, which is consistent with present rates of deposition. However suggestions that Newfoundland could be considered an unaffected region (Harvey et al. 1981) are not entirely valid.

Several lakes in this study showing alteration of chemical status were highly coloured, making it difficult to isolate the roles of natural organic acidity and mineral acidity of anthropogenic origin. Many small lakes in insular Newfoundland are highly coloured, correlating to high levels of organic acidity. Organic acidity is contributing to pH decline and appears to mobilize aluminum and manganese. It is likely organics are chelating these metals, thereby influencing their potential toxicity to aquatic biota. Levels of aluminum and manganese in lake water were less than those documented for affected regions of the world (Harvey et al. 1981), but measurement of total aluminum and total manganese did not permit evaluation of the levels of potentially toxic species. Research is presently ongoing in these areas (see Glass et al. 1981; Kerekes 1982) and results of this research will assist in the evaluation of acidification in insular Newfoundland.

There is no concrete evidence of affected fish populations in relation to chemical status of lakes but fish presence/absence has been related to lake pH. Levels of trace metals in fish tissue for the most part represent background levels. Fish in several lakes demonstrate mercury levels in excess of the accepted National Health and Welfare minimum standard of 0.5 ppm.

Current research into temporal variability in water quality of selected major Atlantic salmon rivers on the island indicates that highly sensitive systems demonstrate wide fluctuations in key water quality parameters (D. Scruton, unpublished data). Several rivers have demonstrated seasonal depletion of buffering capacity and declines in pH of 2.0 units or more reaching levels that potentially threaten aquatic biota.

A further evaluation of the process of acidification in insular Newfoundland awaits a finer resolution of deposition in spatial and temporal terms. Presently rainfall acidity appears to be approaching levels whereby sensitive regions in the world have documented acidification impacts (Overrein et al. 1980; Harvey et al. 1981). Many regions of the province receive high annual precipitation, which can act to increase relative acid loadings. Forecasts of future rates of deposition are highly tenuous, but increased high sulphur coal consumption by thermal power plants in Cape Breton, Nova Scotia is likely to result in increased deposition of sulphate in insular Newfoundland, particularly along the south coast.

Considering the global experience with respect to acid deposition and the sensitivity of Newfoundland freshwaters, we may be on the threshold of an acidification problem here in Newfoundland. Two areas that are likely to be most impacted by potential acidification are the south coast region (particularly the southwest portion) and the southeastern portion of the Northern Peninsula. Future research efforts should be concentrated in these two regions. Considering the present and forecast deposition, freshwaters along the south coast would appear to be most threatened.

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Table 1. Water quality parameters measured, analytical methods, and detection limits.

Parameter	Analytical Procedure	Required Vol. (ml)	Limit of Detection (mg/L)
Conductivity	Radiometer Conductivity Meter	20	0.5 (μScm^{-1})
Colour	Visual Comparison using Platinum Colour Plasma	10	5 (TCU)
pH	Combination Glass & Reference Electrode Radiometer pH Meter	8	0.01 (pH units)
Turbidity	Nephelometric Method	10	- (JTU)
Sodium	Atomic Absorption	2	0.1
Potassium	Atomic Absorption	2	0.02
Calcium	Atomic Absorption	2	0.01
Magnesium	Atomic Absorption	2	0.02
Alkalinity	Auto Analyzer Colormetric Bromophenol Blue	8	0.1
Sulfate	Auto Analyzer Colormetric Methylthymol Blue	8	0.3
Chloride	Auto Analyzer Colormetric Mercuric Thiocyanate	8	0.1
Phosphate total as P	Auto Analyzer Colormetric-U.V. Digestion & Molybate Ascorbic Acid	8	0.001
Nitrogen total as N	Auto Analyzer Colormetric-U.V. Digestion & Diazotization	8	0.02
Aluminum	Atomic Absorption - HGA (Heated Graphite Atomizer)	50	0.010

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Table 1. (Cont'd.)

Parameter	Analytical Procedure	Required Vol. (ml)	Limit of Detection (mg/L)
Zinc	Atomic Absorption - HGA (Heated Graphite Atomizer)	50	0.002
Nickel	Atomic Absorption - HGA (Heated Graphite Atomizer)	50	0.001
Copper	Atomic Absorption - HGA (Heated Graphite Atomizer)	50	0.0015
Lead	Atomic Absorption - HGA (Heated Graphite Atomizer)	50	0.001
Cadmium	Atomic Absorption - HGA (Heated Graphite Atomizer)	50	0.0006
Iron	Atomic Absorption - ICP (Inductively Coupled Plasma)	50	0.007
Manganese	Atomic Absorption - ICP (Inductively Coupled Plasma)	50	0.003

Table 2. Atomic absorption variables and detection limits for analyses of eight metals in fish tissue.

Element	Wavelength (nm)	Analytical Procedure	Detection Limit of Digestate (µg/mL)	Concentrations of Standards (µg/mL)	Matrix of Standards
Zinc	213.9	Air Acetylene Direct Aspiration	0.001	0.5, 1.0, 1.5	10% H_2SO_4
Nickel	232.0	Air Acetylene Direct Aspiration	0.05	0.075, 0.1, 0.15	10% H_2SO_4
Cadmium	228.8	Air Acetylene Direct Aspiration	0.005	0.01, 0.05, 0.1	10% H_2SO_4
Manganese	279.5	Air Acetylene Direct Aspiration	0.01	0.05, 0.1, 0.2	20% H_2SO_4
Aluminum	309.3	Nitrous Oxide Acetylene Direct Aspiration	0.1	05, 1.0, 2.0	20% H_2SO_4 + 2000 ppm KCl
Mercury	253.7	Automated Cold Vapour	0.0002	0.003, 0.005 0.01, 0.02	Digested with Samples
Arsenic	193.7	Automated Hydride Generation	0.0003	0.002, 0.005, 0.01	10% H_2SO_4
Selenium	196.0	Automated Hydride Generation	0.0005	0.01, 0.05, 0.1, 0.2	10% H_2SO_4

Table 3. Summary of sex and maturity data (by region) for fish captured during the study.

Region	Species	No. of lakes	Number captured	Males			Females		
				No.	%	% Mature	No.	%	% Mature
Northern	Brook trout	13	180	113	63	83	67	37	73
(n=23)	Ouananiche	2	4	1	25	100	3	75	67
	Atlantic salmon	1	3	2	67	50	1	33	100
Central	Ouananiche	13	211	135	64	60	76	36	63
(n=20)	Brook trout	23	200	107	53	65	93	47	90
	Atlantic salmon	2	26	1	4	100	25	96	84
Eastern	Brook trout	18	235	127	54	72	108	46	92
(n=22)	Ouananiche	13	125	64	51	56	61	49	44
	Atlantic salmon	4	11	4	36	75	7	64	74
Avalon	Atlantic salmon	2	7	2	29	50	5	71	100
(n=3)	Brook trout	1	2	2	100	100	0	-	-
	Brown trout	1	2	1	50	100	1	50	100
Southern	Ouananiche	4	64	32	50	28	32	50	56
(n=24)	Brook trout	9	52	26	50	73	26	50	85
	Atlantic salmon	1	2	1	50	100	1	50	100
Western	Brook trout	5	90	49	54	98	41	46	93
(n=7)	Atlantic salmon	1	2	0	-	-	2	100	100
Totals	Brook trout	69	759	424	56	76	335	44	87
(n=109)	Ouananiche	32	404	232	57	55	172	43	55
	Atlantic salmon	11	51	10	20	70	41	80	76
	Brown trout	1	2	1	50	100	1	50	100

Table 4. Summary of length, weight, and age data (by region) for fish captured during the study.

Region	Species	No. of lakes	Number captured	Length (mm)			Weight (g)			Age		
				Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Northern (n=23)	Brook trout	13	180	185	501	269	81	1634	274	2	7	3.8
	Ouananiche	2	4	363	417	390	517	869	693	3	4	3.5
	Atlantic salmon	1	3	145	502	340	29	1369	651	2	5	3.3
Central (n=20)	Ouananiche	13	211	170	535	292	36	1943	291	2	8	4.5
	Brook trout	23	200	134	439	247	26	1597	199	2	7	3.5
	Atlantic salmon	2	26	404	587	480	536	1910	1105	3	5	4.6
Eastern (n=22)	Brook trout	18	235	175	450	272	67	1066	278	2	7	3.7
	Ouananiche	13	125	168	539	285	57	1361	271	2	7	4.7
	Atlantic salmon	4	11	174	570	364	60	1361	497	3	7	4.6
Avalon (n=3)	Atlantic salmon	2	7	412	541	491	454	2268	1247	3	5	4.5
	Brook trout	1	2	244	249	246	154	185	170	3	3	3.0
	Brown trout	1	2	477	496	486	1247	1361	1304	5	5	5.0
Southern (n=24)	Ouananiche	4	64	135	397	308	27	749	342	2	7	4.8
	Brook trout	9	52	174	429	252	52	795	220	2	7	3.6
	Atlantic salmon	1	2	520	545	532	1091	1207	1149	5	5	5.0
Western (n=7)	Brook trout	5	90	179	453	270	61	1234	289	2	7	3.4
	Atlantic salmon	1	2	587	600	593	1845	1952	1898	6	6	6.0
Totals (n=109)	Brook trout	69	759	134	501	263	26	1634	240	2	7	3.6
	Ouananiche	32	404	135	539	296	27	1943	297	2	8	4.6
	Atlantic salmon	11	51	145	600	454	29	2268	999	2	7	4.6
	Brown trout	1	2	477	496	486	1247	1361	1304	5	5	5.0

Table 5. CPUE statistics for brook trout (Salvelinus fontinalis) by region, geological type, pH and lake size.

	No. of lakes	CPUE (no.)			CPUE (wt. in g)		
		Mean	Min.	Max.	Mean	Min.	Max.
REGION							
Northern	14	6.7	0.4	23.1	2,395	44	13,119
Central	24	4.6	0.3	24.9	889	32	4,283
Eastern	18	8.2	0.9	31.3	2,227	90	1,026
Avalon	1	1.2	-	-	198	-	-
Southern	13	1.7	0.5	3.3	393	45	994
Western	5	9.2	0.5	27.3	2,724	77	10,964
GEOLOGICAL TYPE							
Conglom./Sandst.	1	8.9	-	-	797	-	-
Limestone	6	10.6	2.1	23.1	4,771	289	13,319
Siltstone	4	4.2	0.5	10.2	1,486	45	4,263
Gneiss	8	2.6	0.4	7.3	432	44	989
Granite	35	5.4	0.3	28.5	1,359	32	10,964
Gabbro	1	31.3	-	-	12,052	-	-
Volcanics	11	3.8	6.0	10.8	615	85	4,283
pH							
4.5-5.0	1	2.1	-	-	365	-	-
5.0-5.5	6	2.3	0.5	5.0	646	58	1,438
5.5-6.0	23	4.4	0.4	28.5	864	44	5,208
6.0-6.5	23	6.6	0.3	31.3	1,591	32	12,053
6.5-7.0	12	4.0	0.5	10.8	786	63	4,263
7.0-7.5	6	10.0	1.4	27.3	3,017	289	10,964
7.5-8.0	4	11.3	6.0	23.1	6,411	1,738	13,319
LAKE AREA (ha)							
10- 50	21	7.8	0.5	27.3	2,242	77	13,319
50- 100	22	5.1	0.3	31.3	1,311	32	12,053
100- 250	23	4.4	0.5	28.5	1,159	45	5,065
250- 500	6	6.5	0.6	24.9	1,600	62	8,705
500-1000	2	1.6	1.0	2.3	529	482	2,893
>1000	1	1.8	-	-	634	-	-

Table 6. CPUE statistics for ouananiche (Salmo salar) by region, geological type, pH and lake size.

	No. of lakes	CPUE (no.) Mean	Min.	Max.	CPUE (wt. in g) Mean	Min.	Max.
REGION							
Northern	1	0.7	-	-	482	-	-
Central	11	10.9	1.1	25.7	3,319	39	8,705
Eastern	13	7.0	0.9	14.0	1,905	214	5,065
Southern	4	5.8	2.1	10.1	1,996	322	3,606
GEOLOGICAL TYPE							
Limestone	1	0.7	-	-	482	-	-
Siltstone	2	3.6	0.6	6.6	844	75	1,613
Granite	15	7.9	0.9	25.7	2,358	214	8,705
Gabbro	1	2.0	-	-	864	-	-
Volcanics	8	8.8	1.1	14.0	2,761	39	5,065
pH							
4.5-5.0	1	1.1	-	-	365	-	-
5.0-5.5	0	-	-	-	646	58	1,438
5.5-6.0	5	7.6	1.8	14.0	2,271	214	5,065
6.0-6.5	16	7.5	0.6	16.0	2,194	75	5,007
6.5-7.0	6	11.9	5.3	25.7	3,610	625	8,705
7.0-7.5	2	2.2	0.7	3.6	826	482	1,170
7.5-8.0	0	-	-	-	-	-	-
LAKE AREA (ha)							
10- 50	4	2.9	0.7	8.9	987	39	3,209
50- 100	8	8.5	2.1	14.0	2,786	626	5,065
100- 250	11	10.2	0.6	25.7	2,813	75	8,705
250- 500	5	4.6	1.8	9.8	1,184	214	2,893
500-1000	1	8.2	-	-	3,606	-	-
>1000	1	12.3	-	-	3,119	-	-

Table 7. Correlation coefficients and slopes ( ) for significant relationships ($P > 0.01$) of linear regression between lake pH and mercury (Hg), aluminum (Al) and manganese (Mn) in fish tissue for brook trout and ouananiche (all lakes combined) by length class increments. Relationships that are not significant ($P > 0.01$) are described as N.S.

Species	Length class (mm)	Fish Hg	Fish Al	Fish Mn
Brook trout	150-200	N.S.	N.S.	0.43 (-0.425)
	200-225	N.S.	N.S.	N.S.
	225-250	N.S.	N.S.	0.34 (-0.218)
	250-275	0.34 (-0.226)	N.S.	N.S.
	275-300	N.S.	N.S.	N.S.
	300-350	0.22 (-0.216)	0.20 (-0.056)	N.S.
	350-400	0.49 (-0.485)	N.S.	N.S.
	400-450	0.60 (-0.875)	N.S.	N.S.
Ouananiche	200-225	0.63 (-0.450)	0.49 (-0.275)	N.S.
	225-250	N.S.	0.46 (-0.275)	N.S.
	250-275	0.42 (-1.067)	N.S.	N.S.
	275-300	0.49 (-1.230)	0.42 (-0.030)	N.S.
	300-350	0.24 (-0.301)	N.S.	N.S.
	350-400	N.S.	N.S.	N.S.

Table 8. Quantification of fisheries habitat at risk and associated salmonid resources.

Anadromous Atlantic Salmon

Geographical region	Statistical area	Riverine Rearing Habitat (x 100 m^2)			Salmon Production Potential (fish)*		
		Access.	Inaccess.	Total	Access.	Inaccess.	Total
Northern Peninsula	04	49,100	8,300	57,400	11,696	1,904	13,600
South Coast	36,37,38,39	93,600	13,300	106,900	53,064	7,236	60,300

*Includes both grilse and large salmon.

Brook Trout, Ouananiche

Geographical region	Land Area (ha)	Freshwater Area (ha)**				Potential Annual Yield (kg/yr)	
		A	%	B	%	A	B
Northern Peninsula	945,923	80,645	9.0	100,267	10.6	294,354	365,974
South Coast	1,466,950	194,385	13.0	158,430	10.8	709,505	578,269

**Freshwater area as estimated by A - Northlands Associates (1982) and B -Whelan and Wiseman (1977).

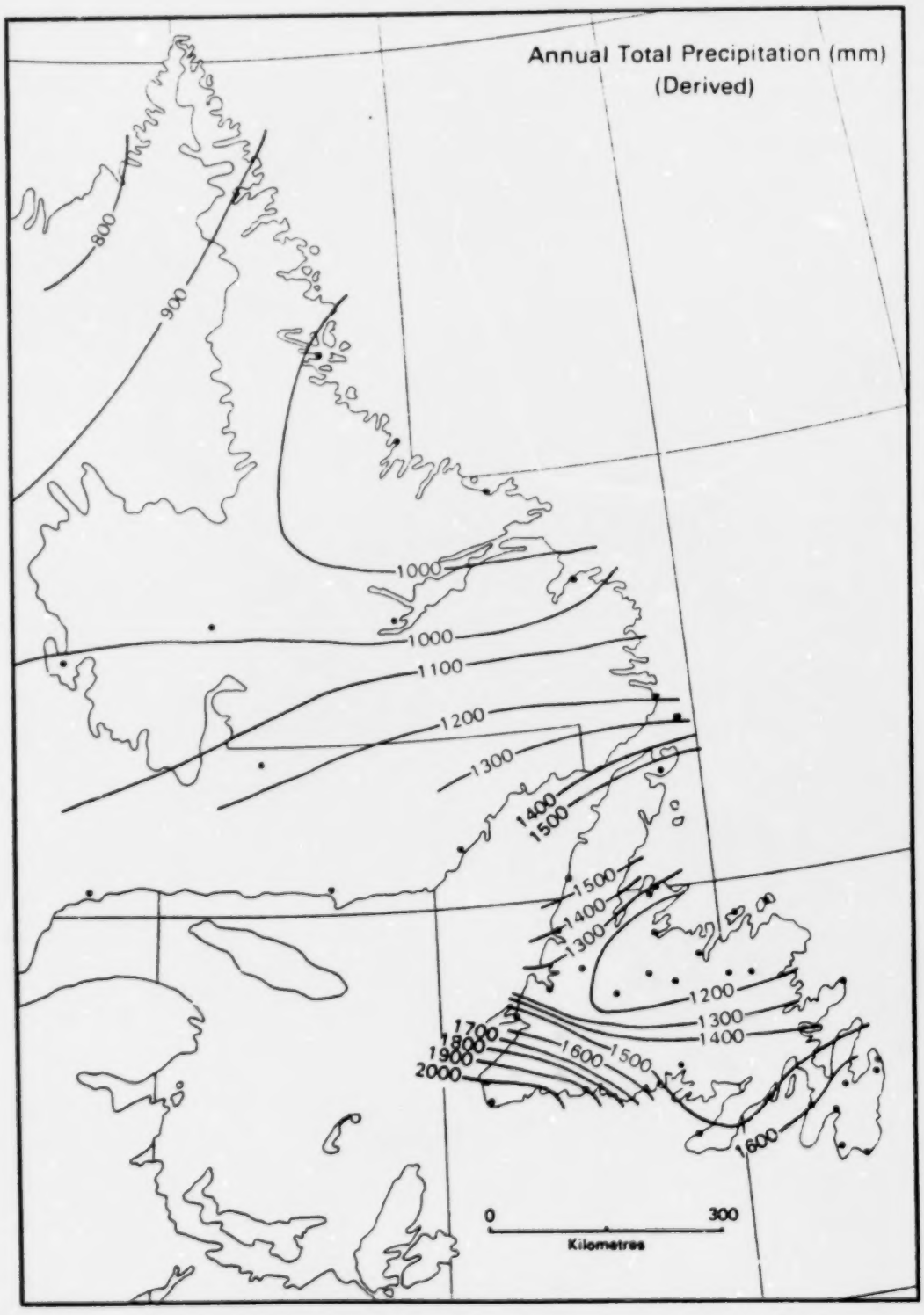

Fig. 1. Mean annual total precipitation (mm) adjusted to be consistent with observed runoff (from MacPherson and MacPherson 1982).

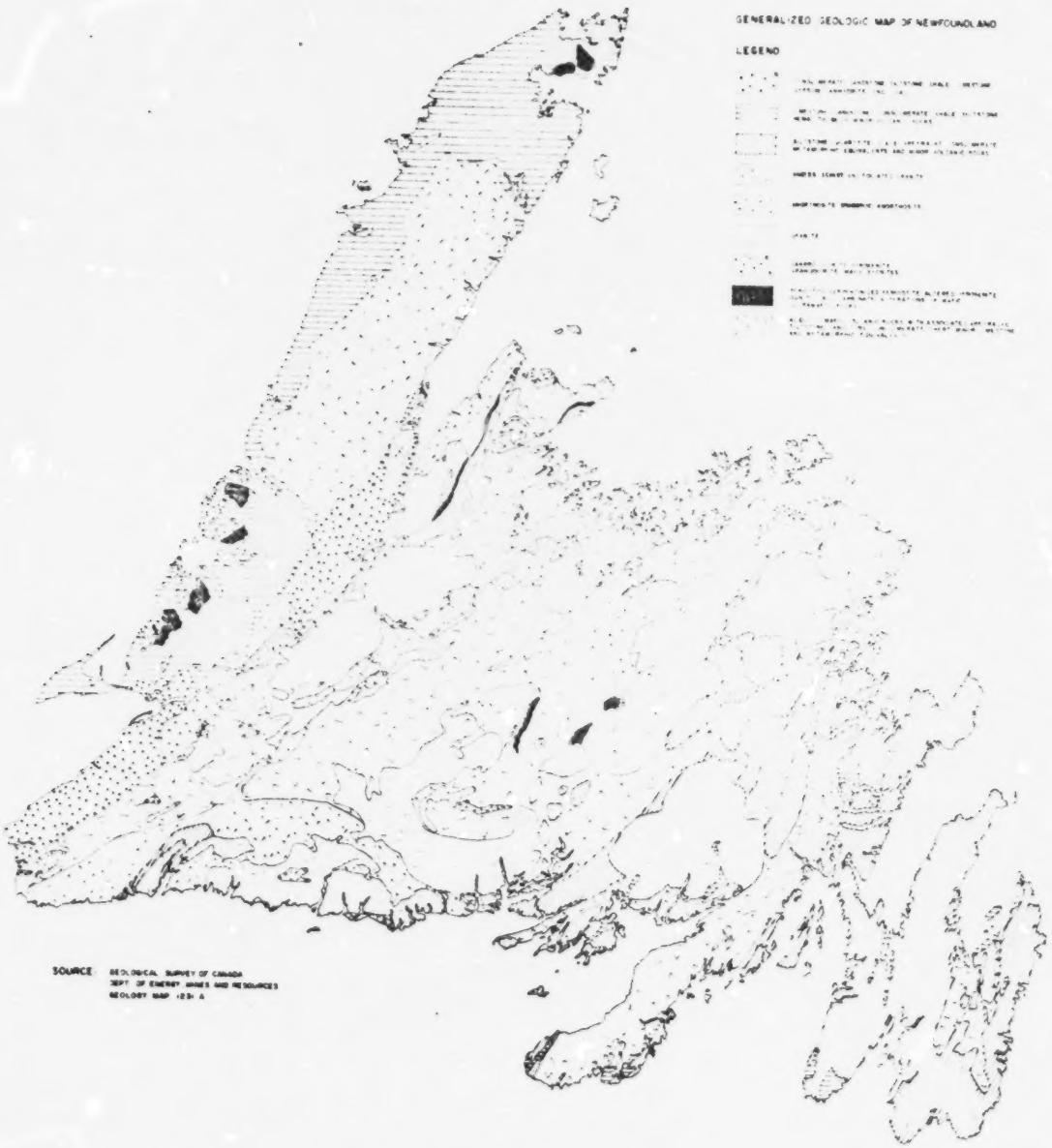

Fig. 2. Bedrock geology of insular Newfoundland.

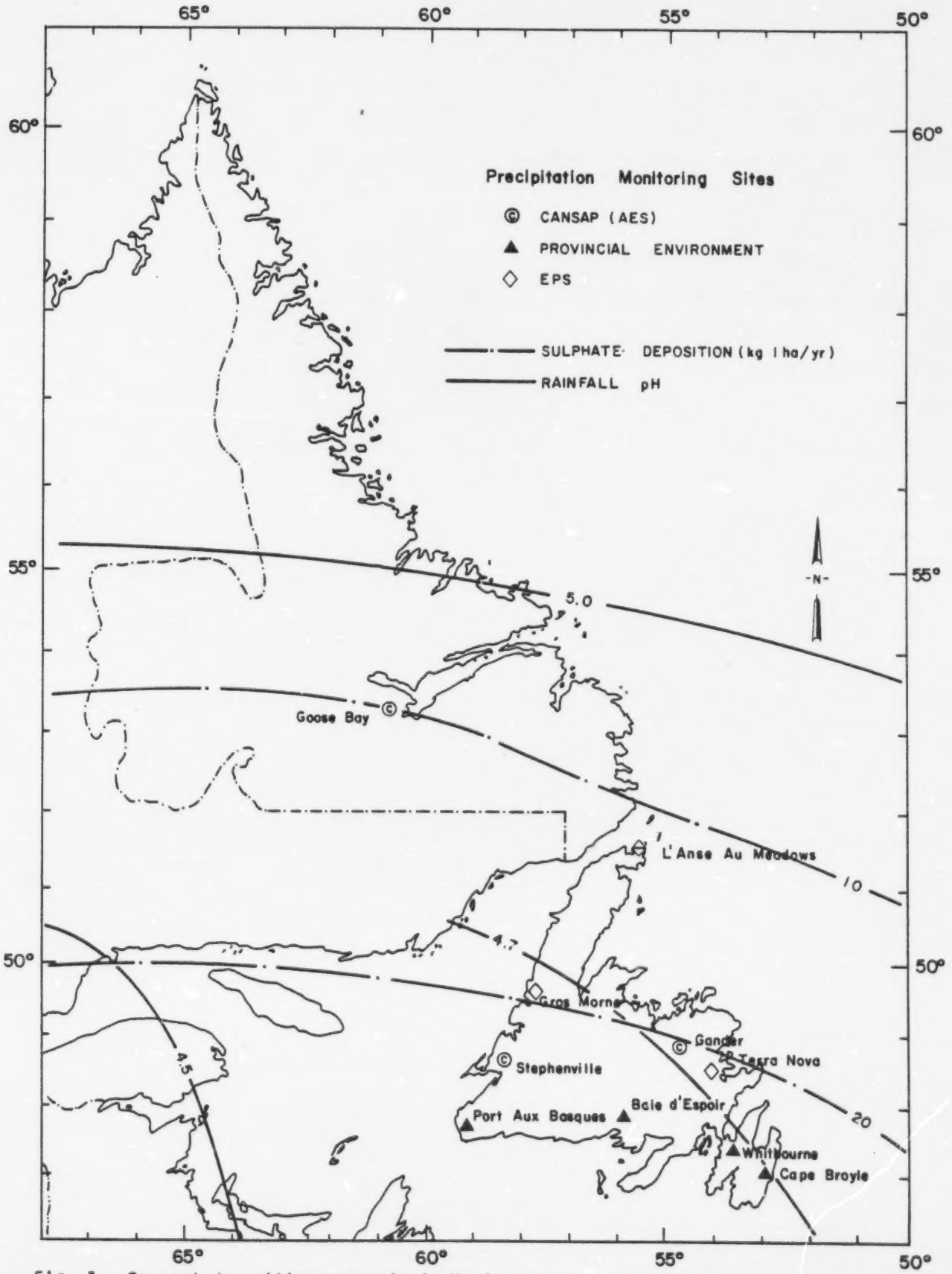

Fig. 3. Present deposition scenario in Newfoundland and Labrador in terms of rainfall pH and sulphate deposition (kg/ha/yr), including location of existing precipitation monitoring sites.

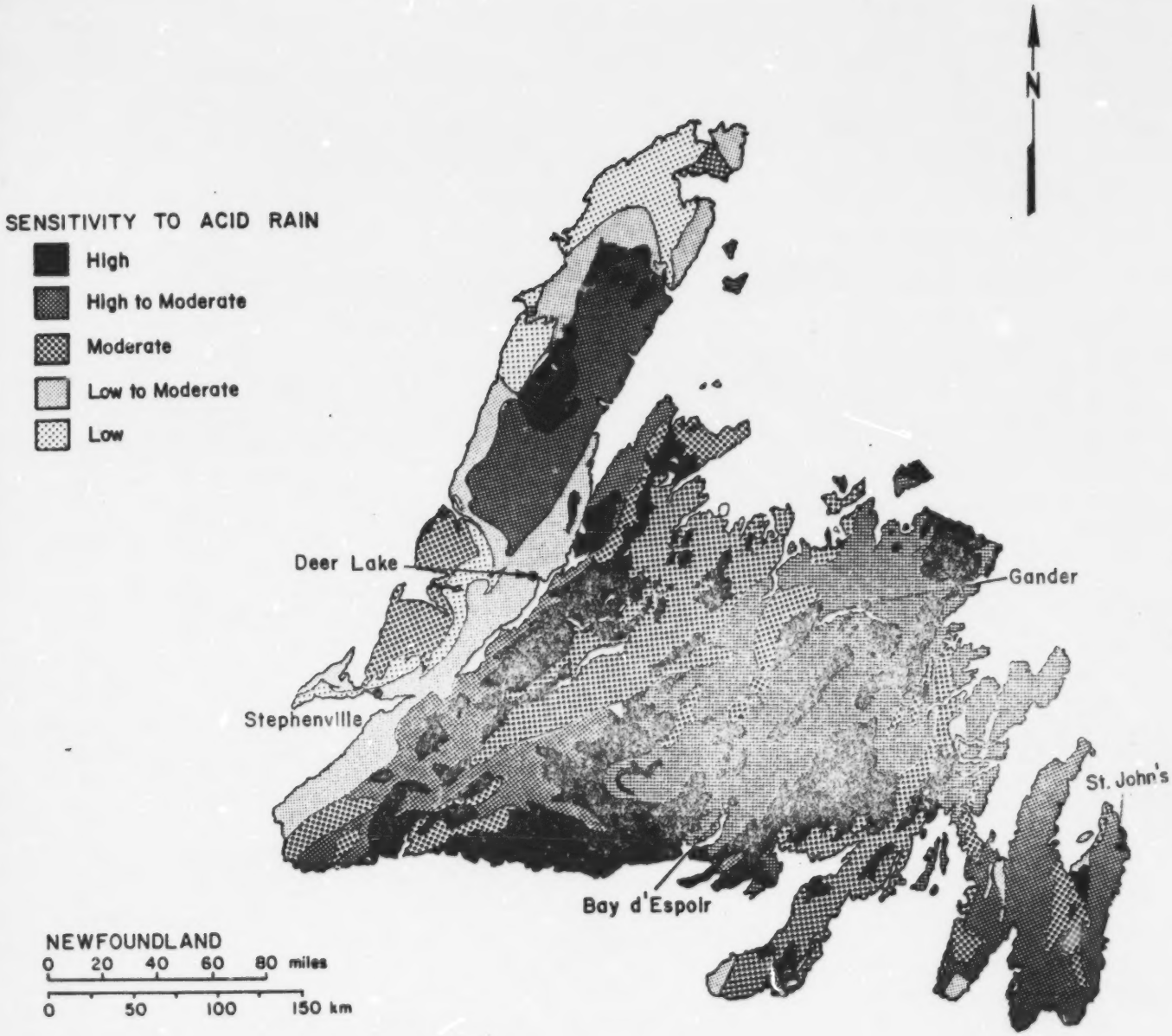

Fig. 4. Sensitivity of insular Newfoundland to acid precipitation, on the basis of bedrock geology (courtesy of Newfoundland Department of Mines and Energy).

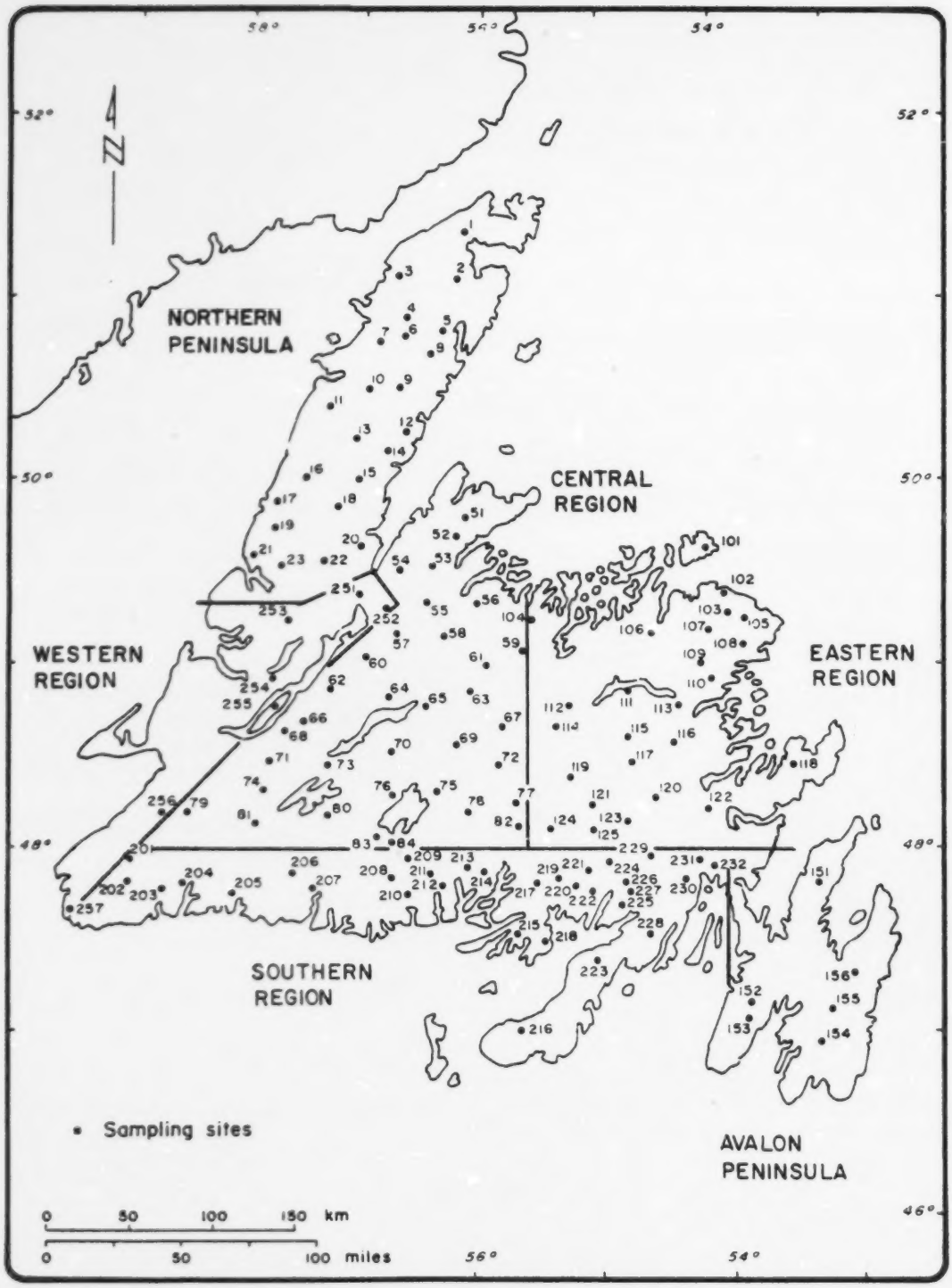

Fig. 5. Map showing lake locations and geographical regions.

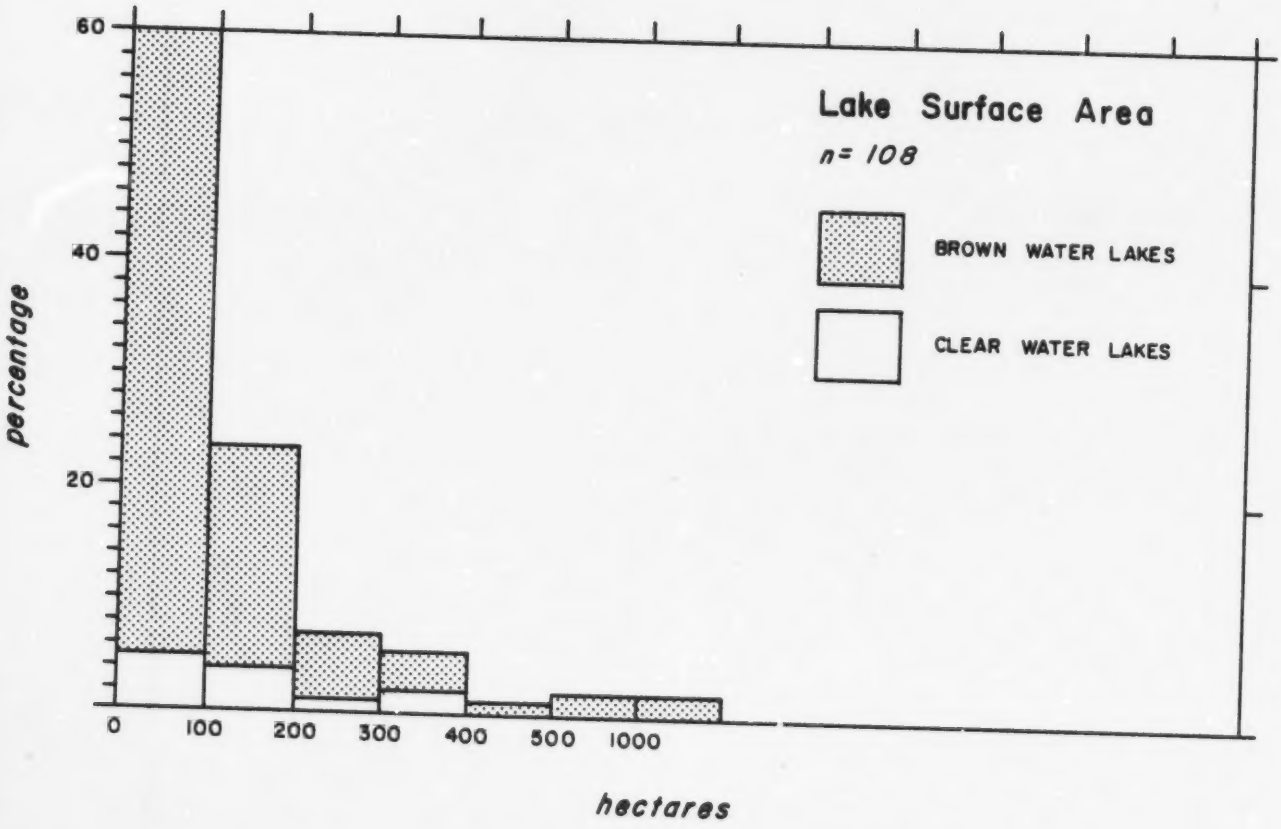

Fig. 6. Distribution of lakes by surface area (hectares).

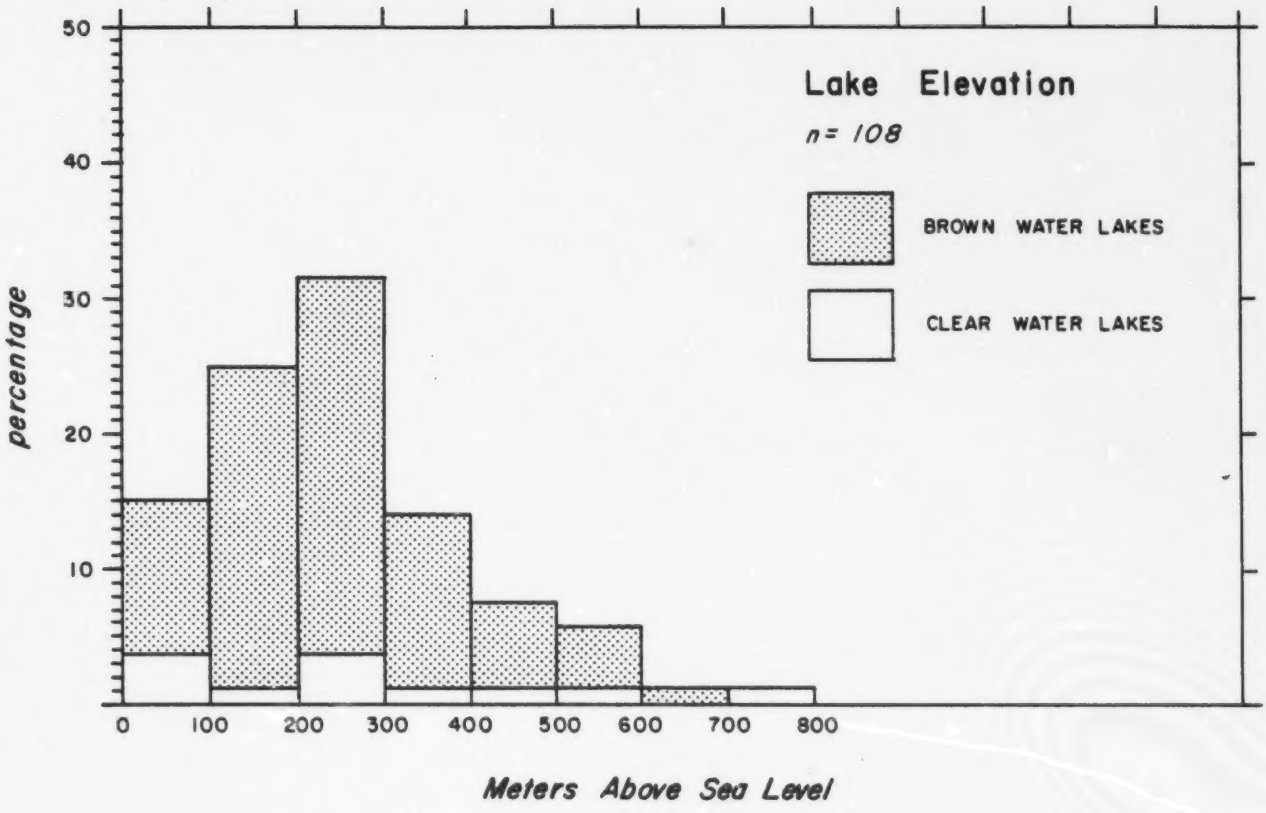

Fig. 7. Distribution of lakes by elevation (meters above sea level).

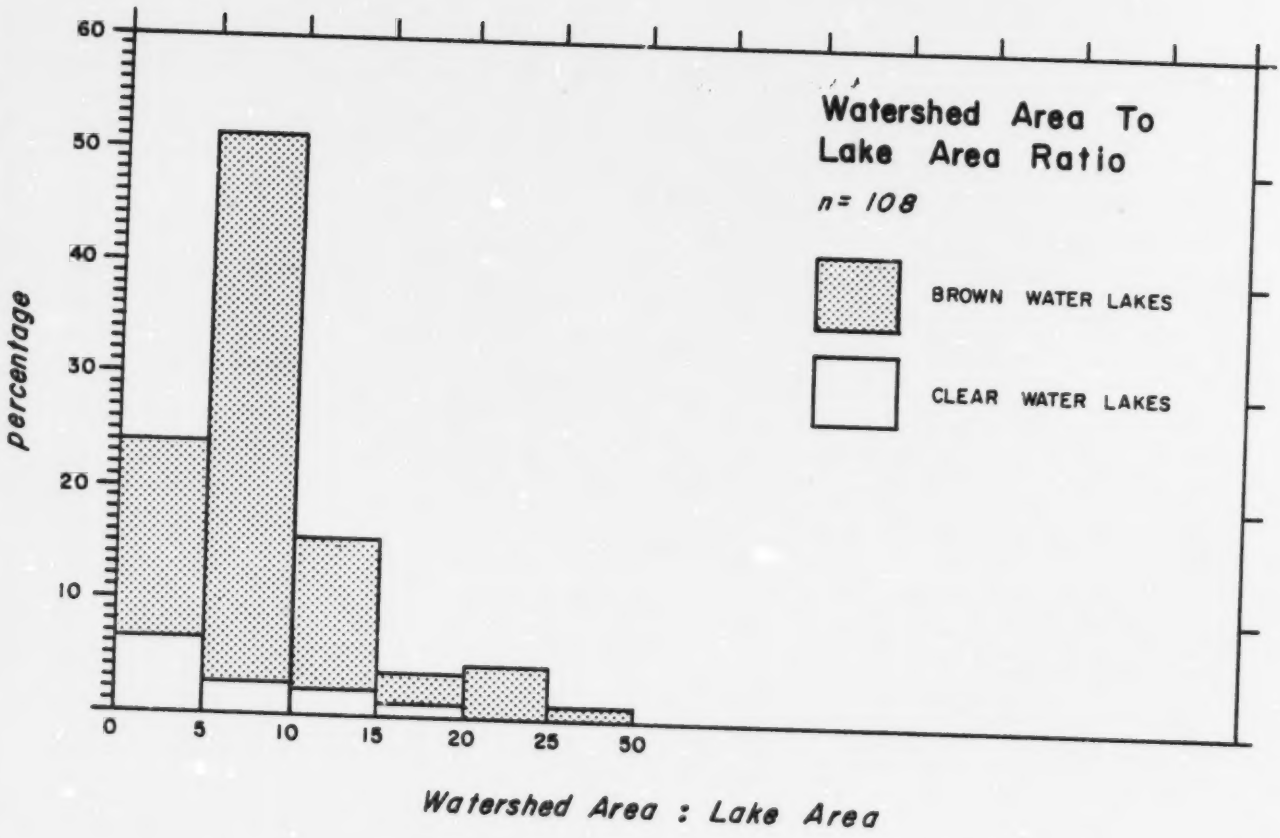

Fig. 8. Distribution of lakes by watershed area to lake surface area ratio (WA:LA).

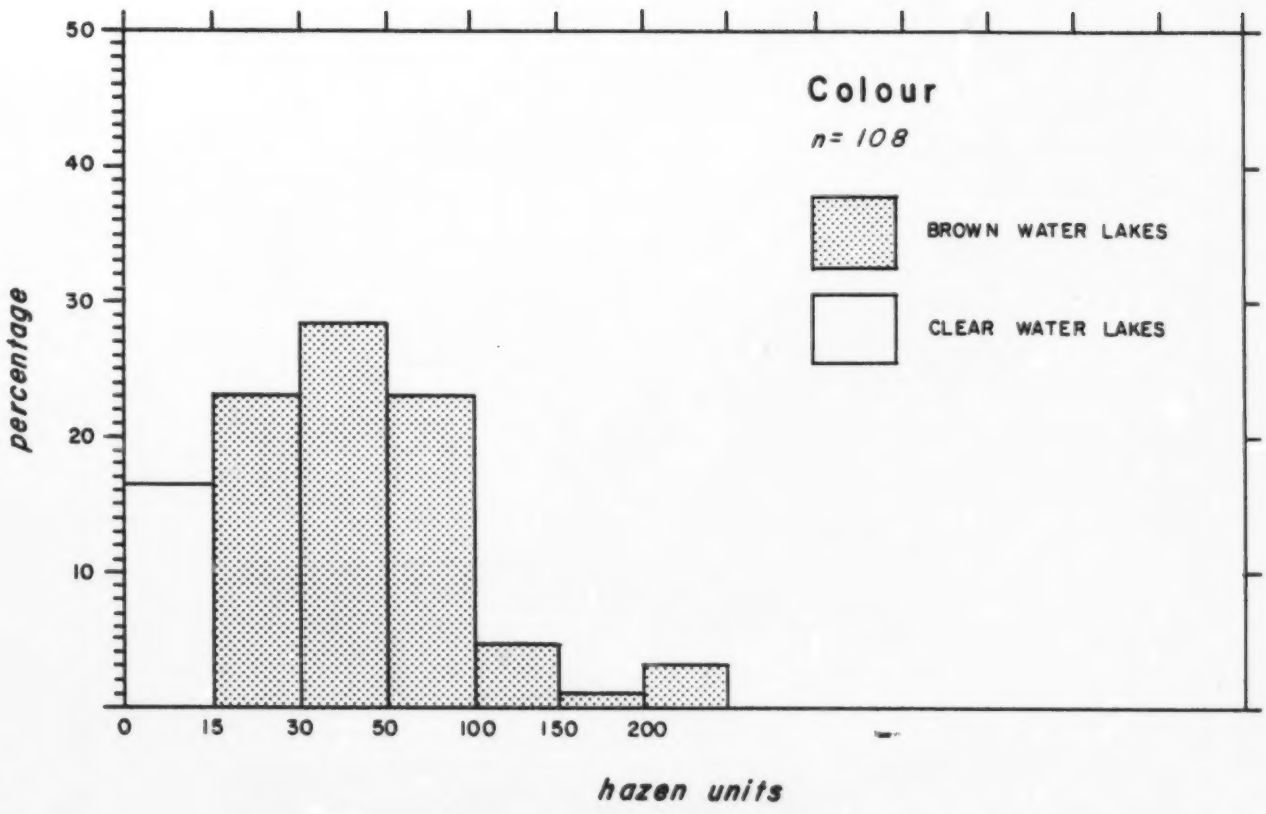

Fig. 9. Distribution of lakes by colour (Total Colour Units).

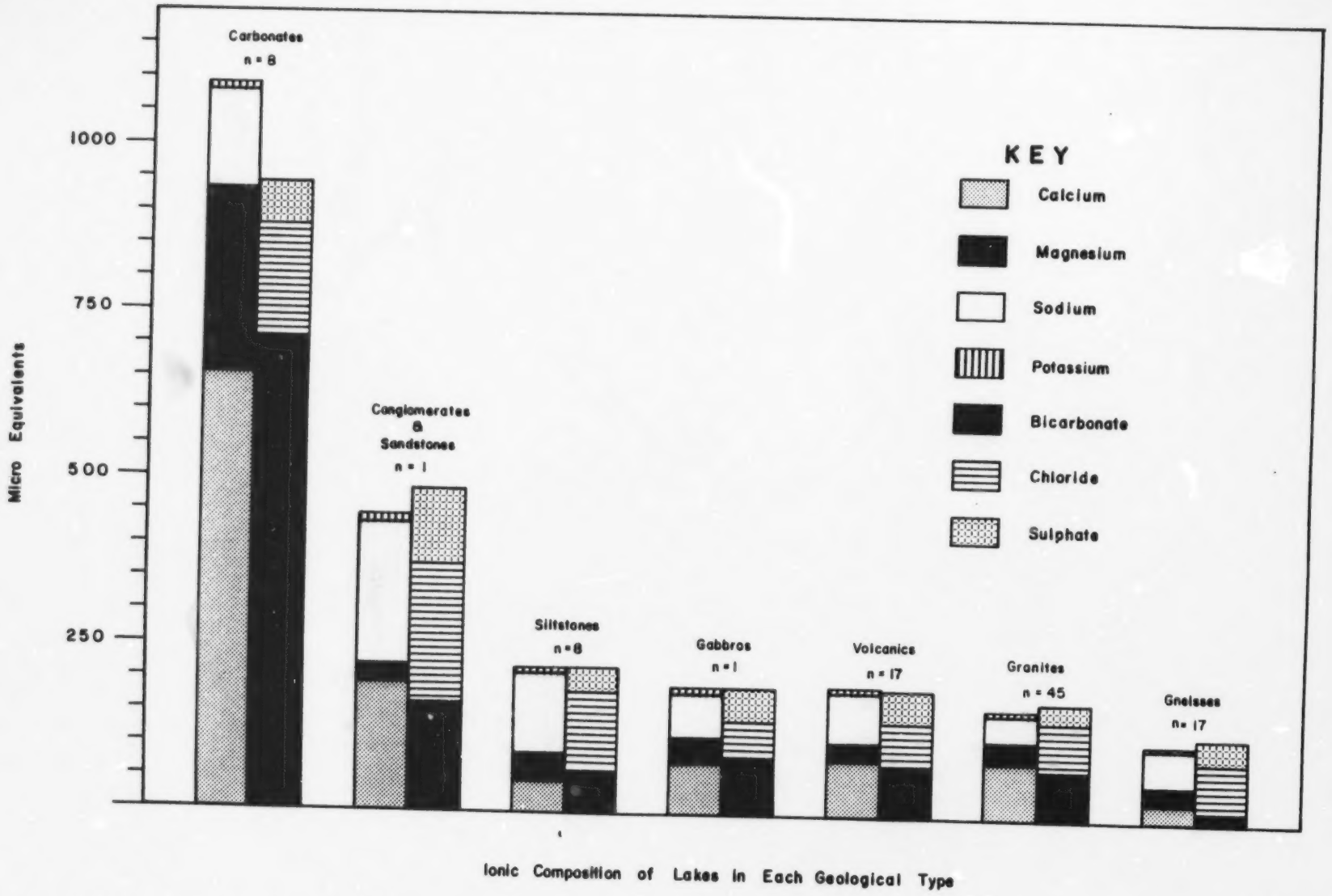

Fig. 10. Mean ionic composition of lakes within each geological type.

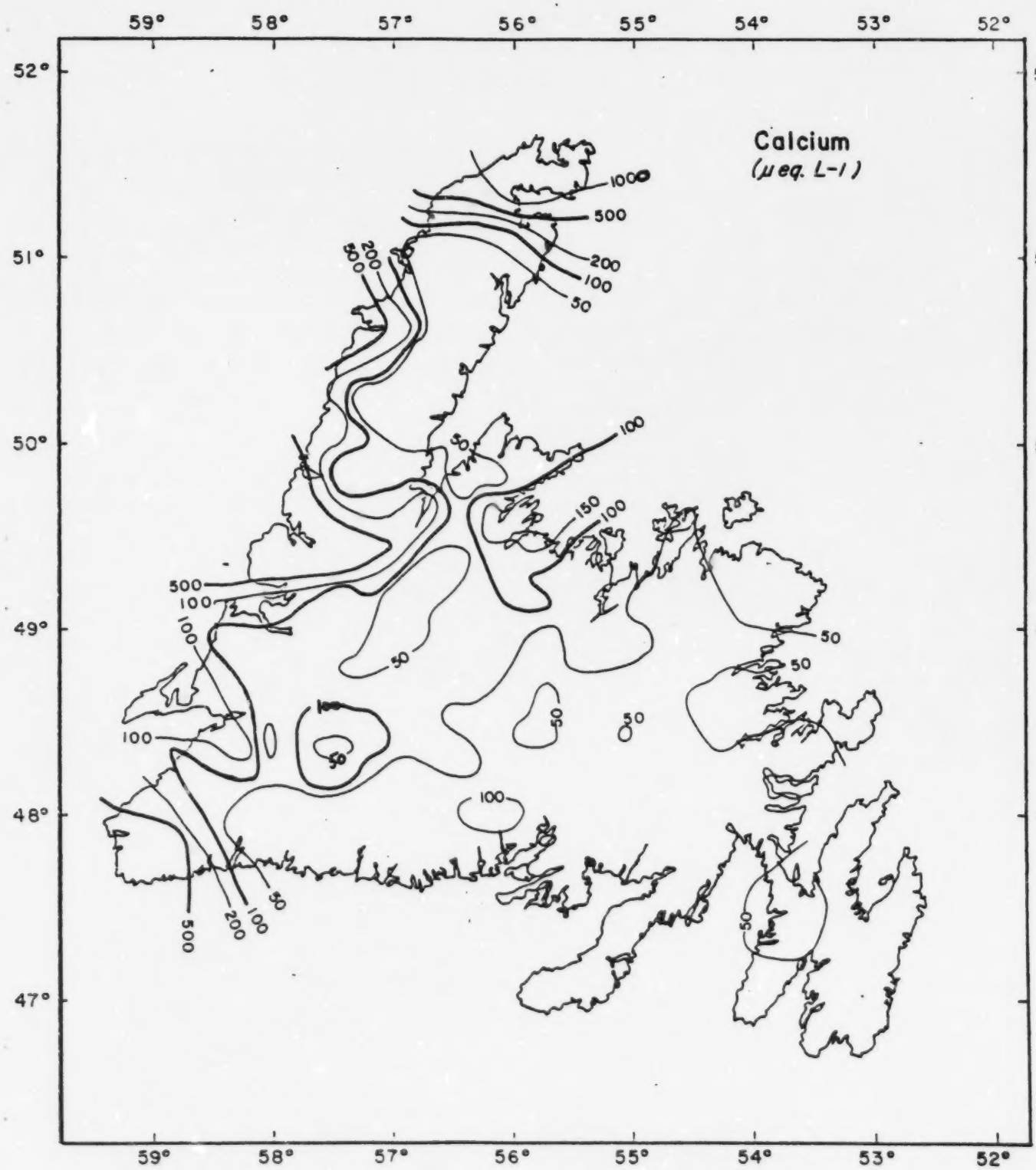

Fig. 11. Spatial distribution of calcium in lake water (μ eq L^{-1}).

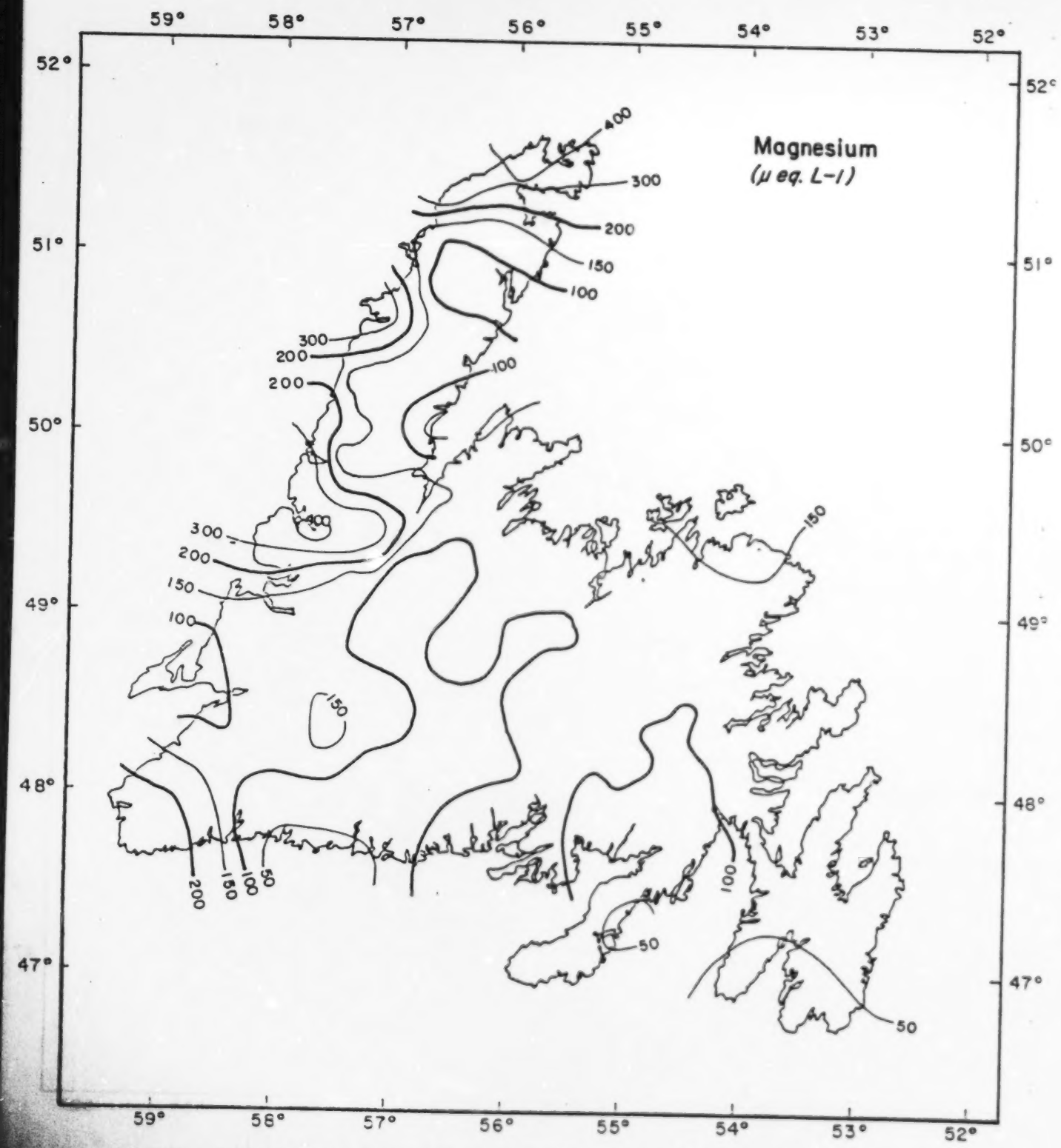

Fig. 12. Spatial distribution of magnesium in lake water (μ eq L^{-1}).

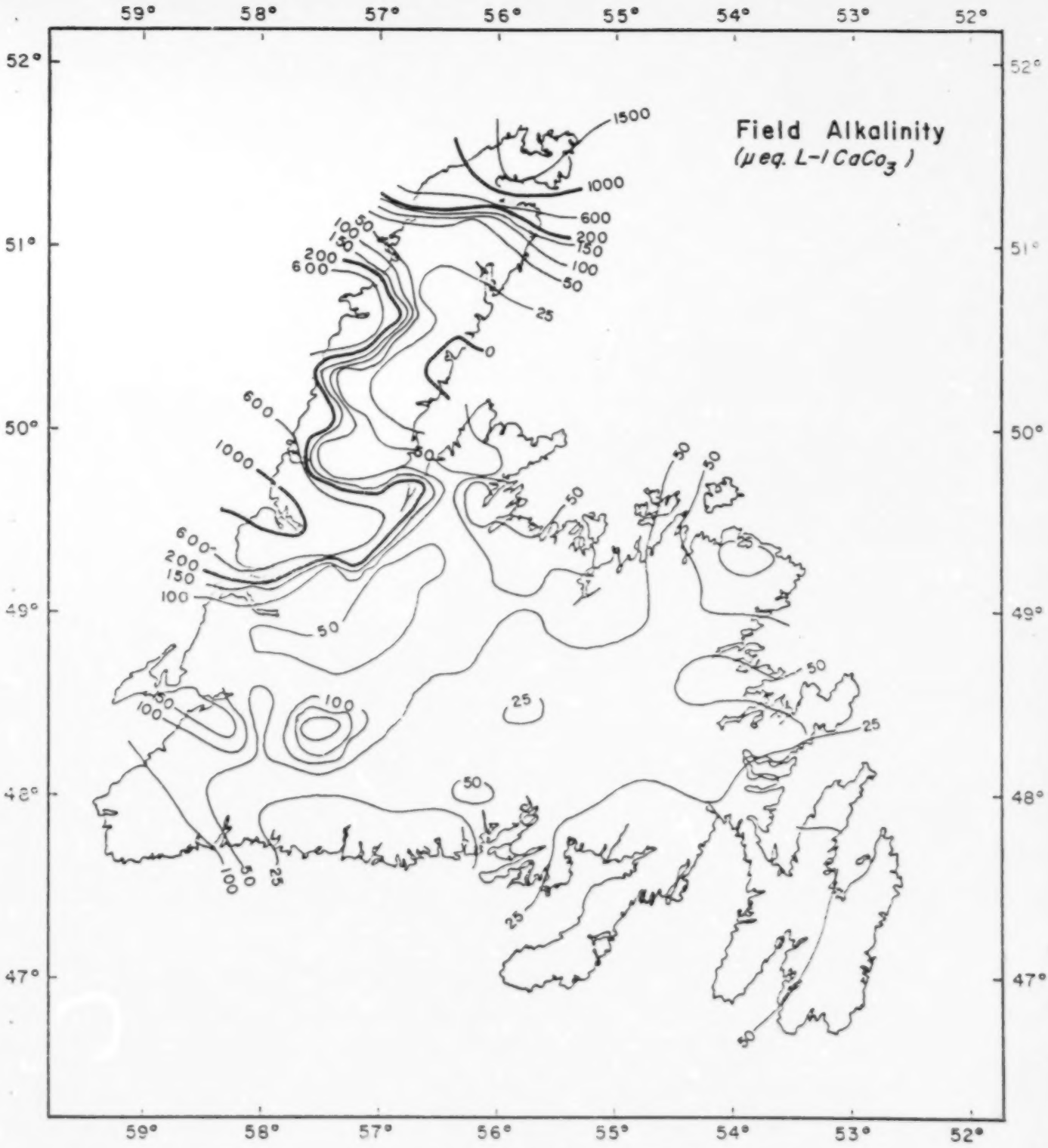

Fig. 13. Spatial distribution of field alkalinities in lake water (μ eq L^{-1}).

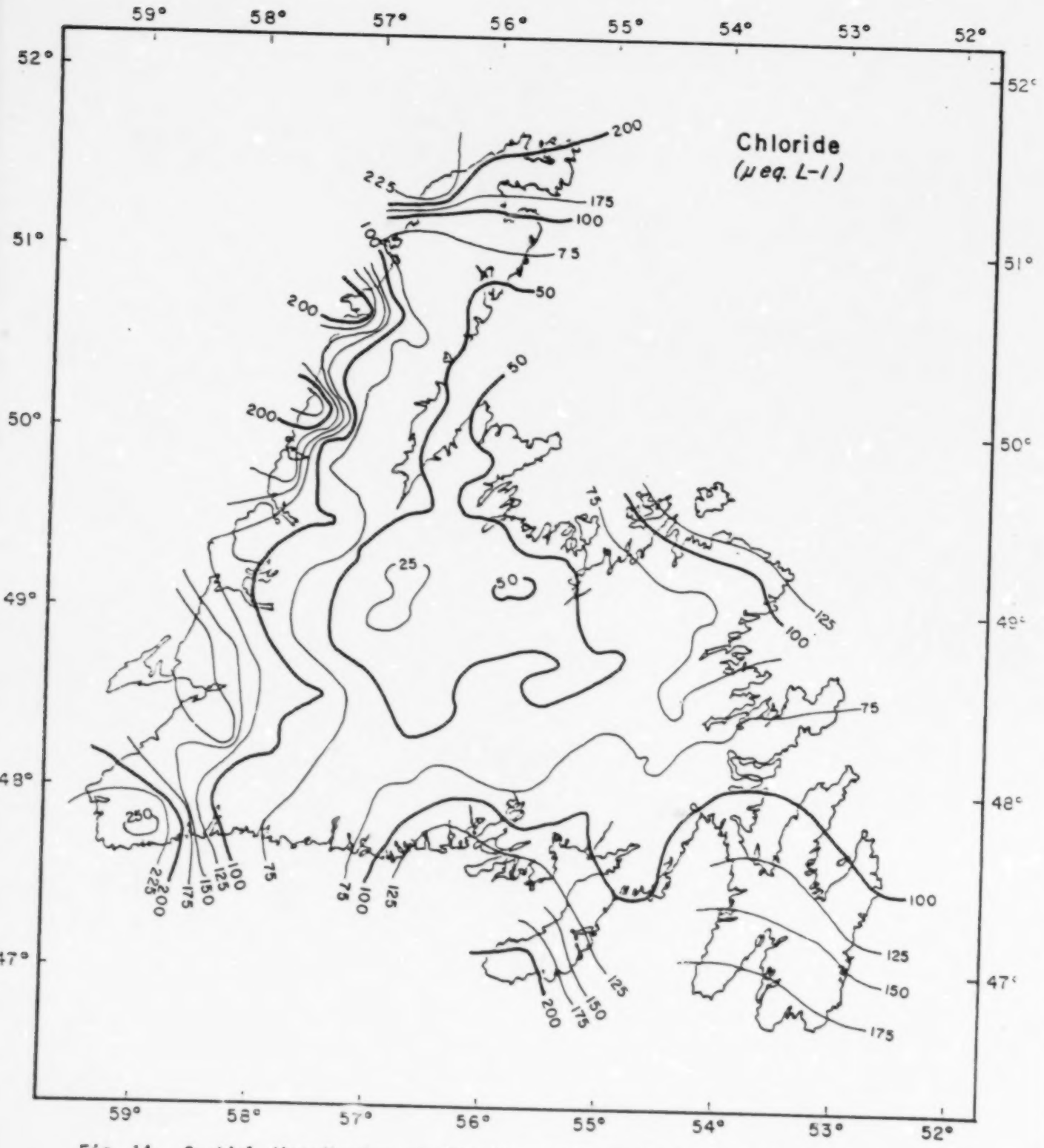

Fig. 14. Spatial distribution of chloride in lake water (μ eq L^{-1}).

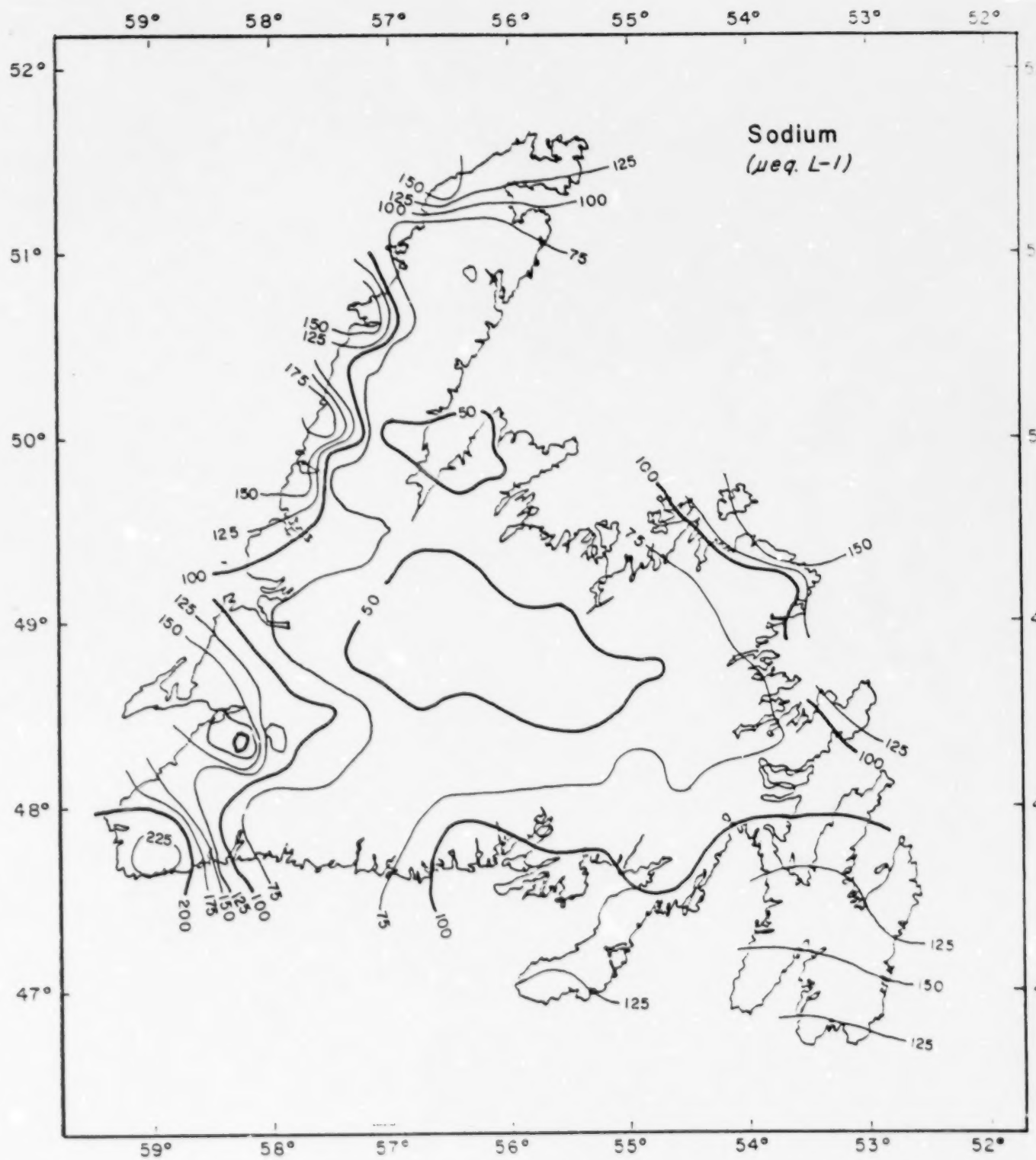

Fig. 15. Spatial distribution of sodium in lake water (μ eq L^{-1}).

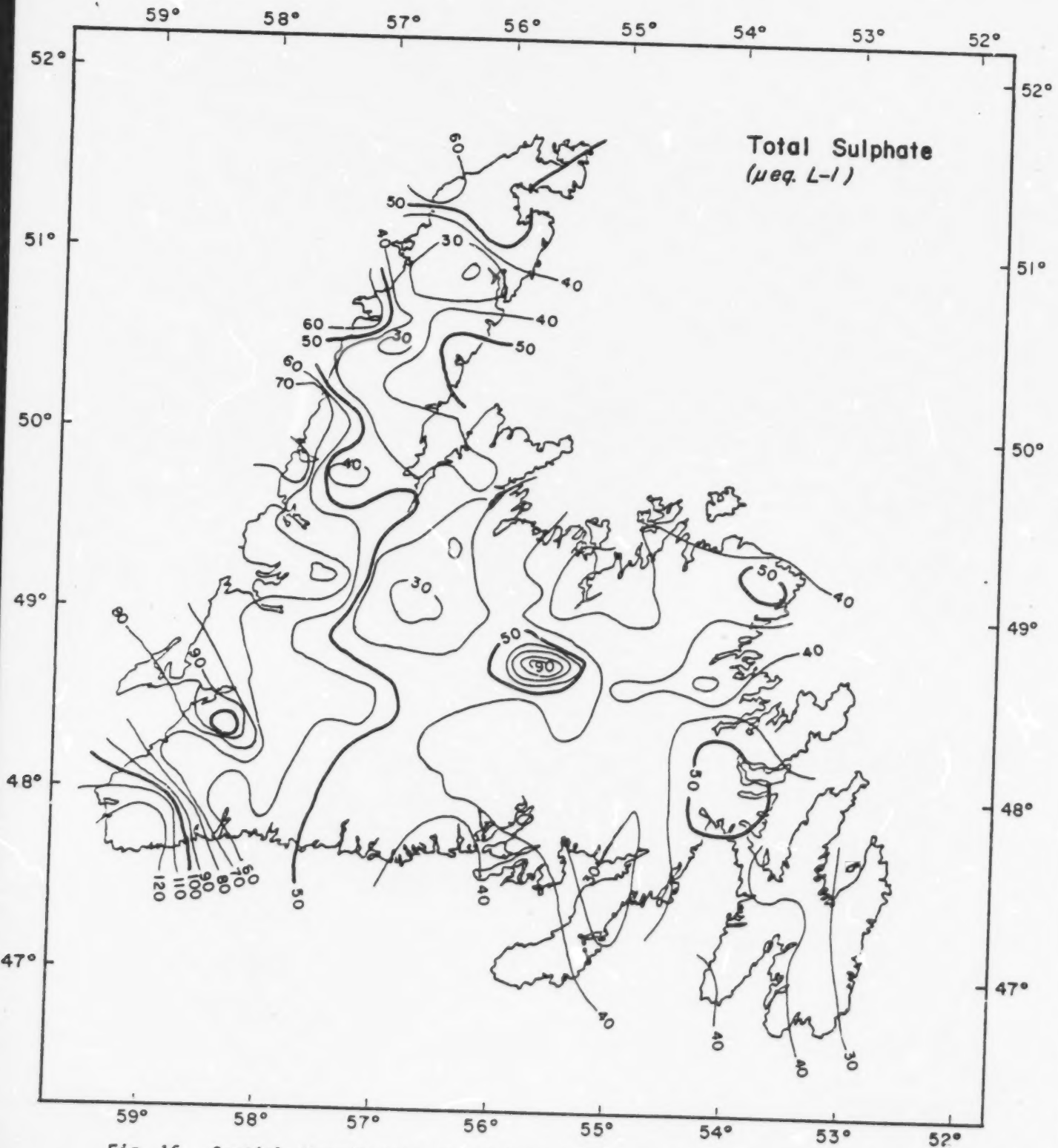

Fig. 16. Spatial distribution of sulphate (total) in lake water (μ eq L^{-1}).

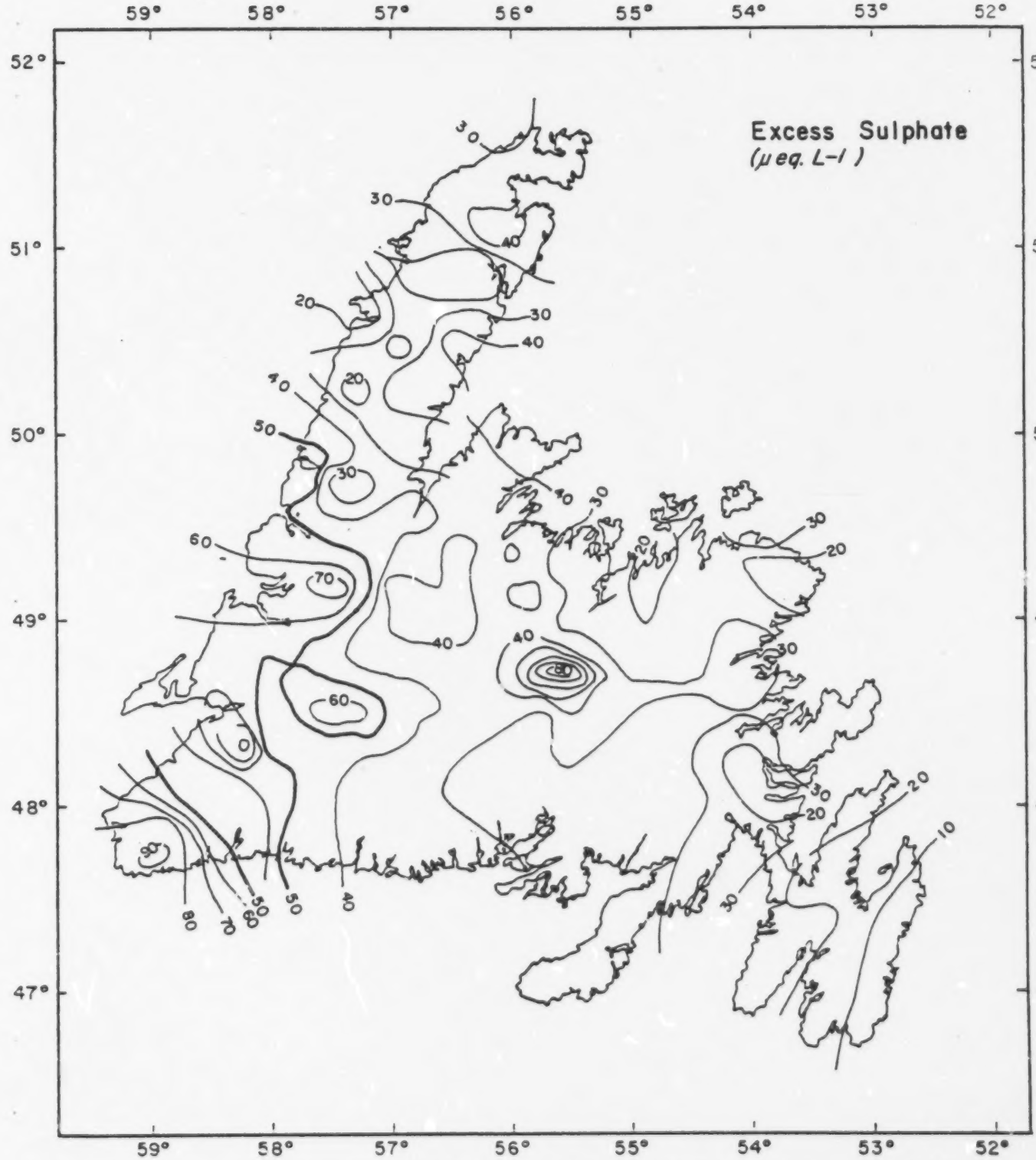

Fig. 17. Spatial distribution of "excess" sulphate in lake water (μ eq L^{-1}).

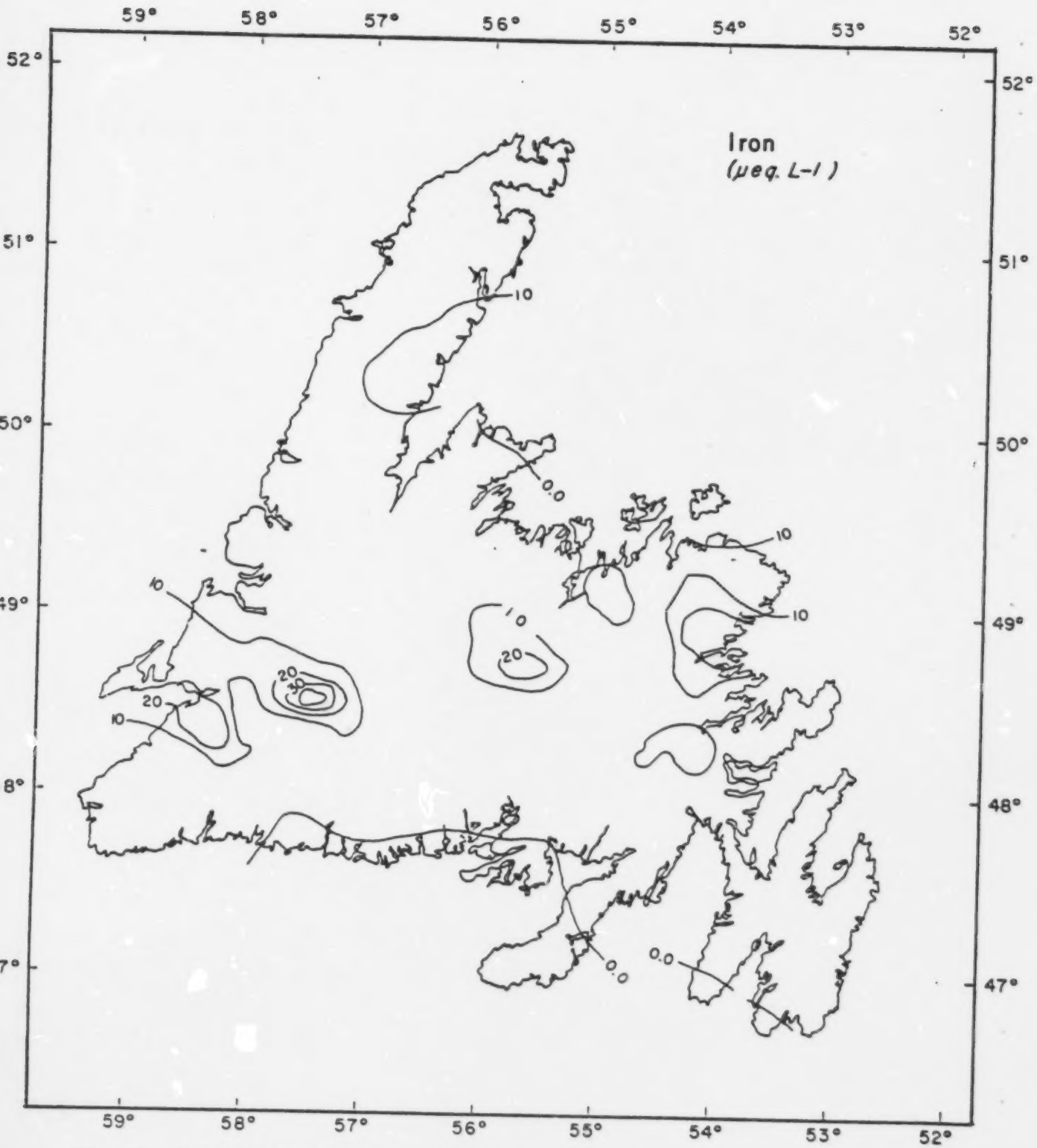

Fig. 18. Spatial distribution of iron in lake water (μ eq L^{-1}).

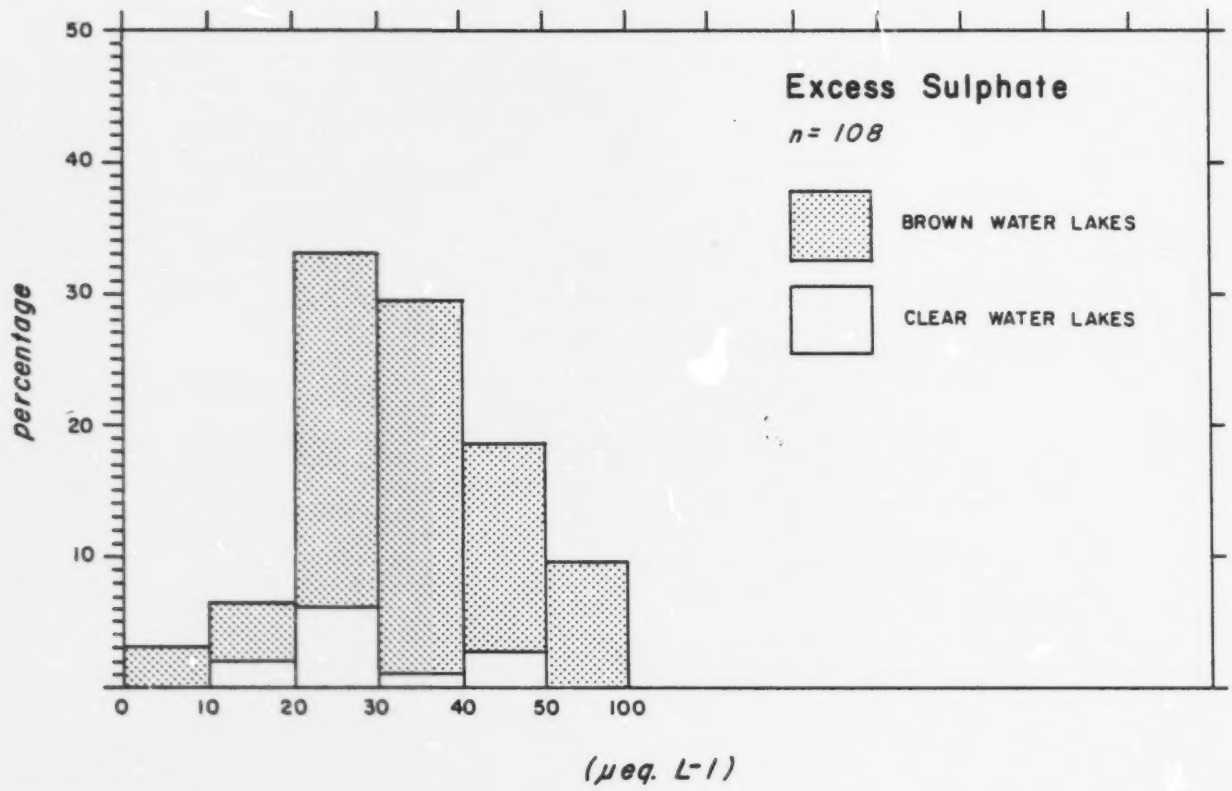

Fig. 19. Distribution of lakes by "excess" sulphate values (μ eq L^{-1}).

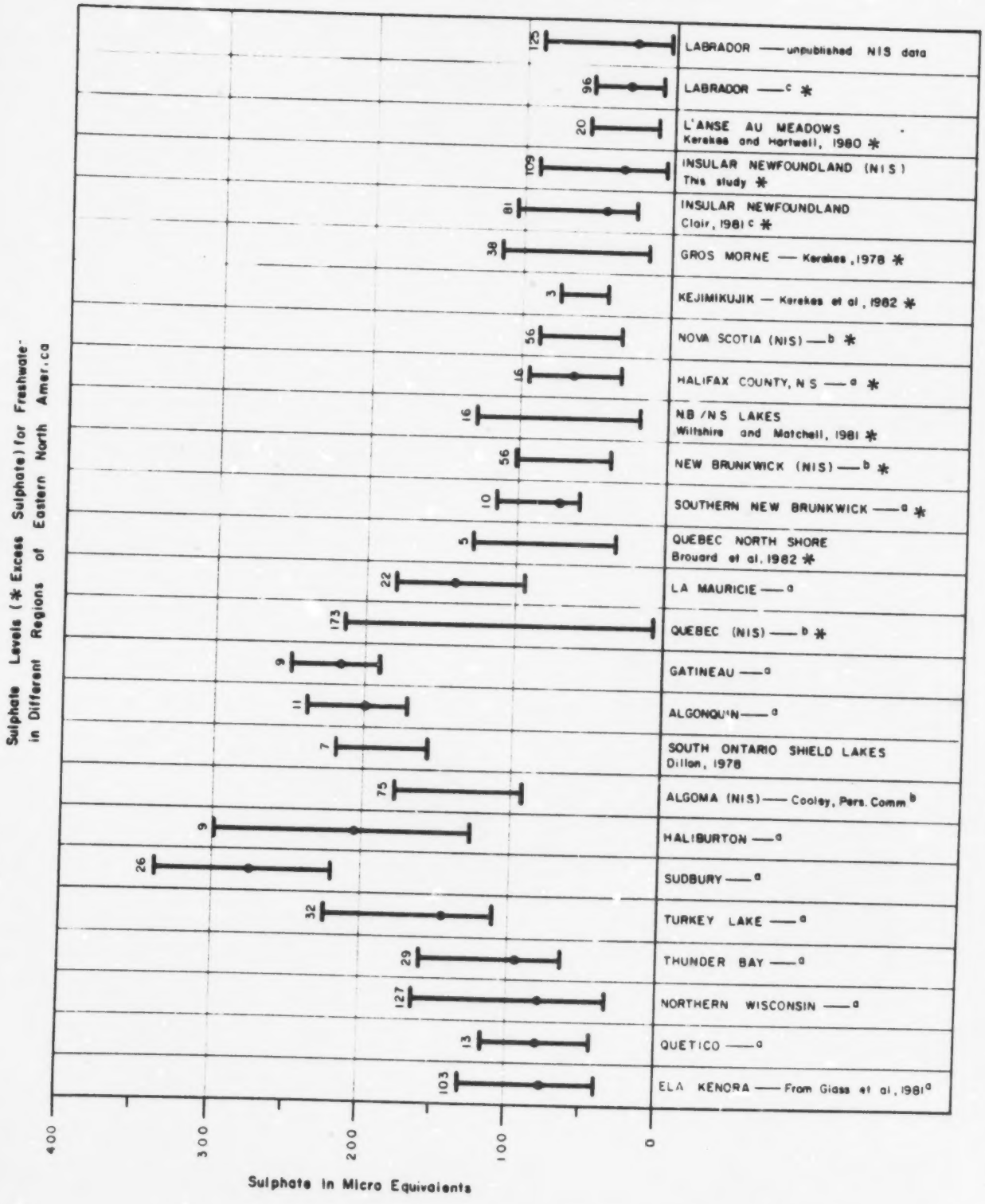

Fig. 20. Sulphate levels ("excess" sulphate in maritime areas) in freshwaters from different regions in eastern North America (adapted after Thompson and Hutton 1982).

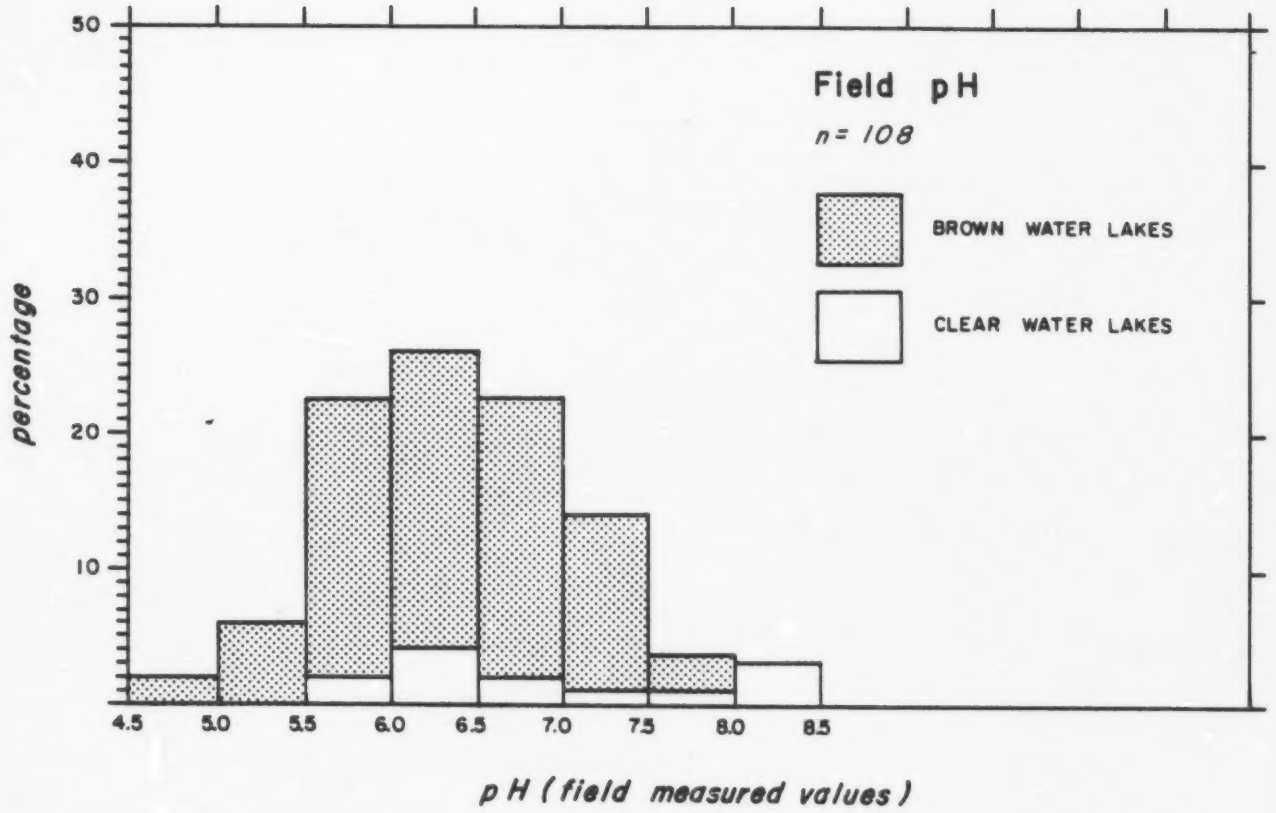

Fig. 21. Distribution of lakes by pH (field measured values).

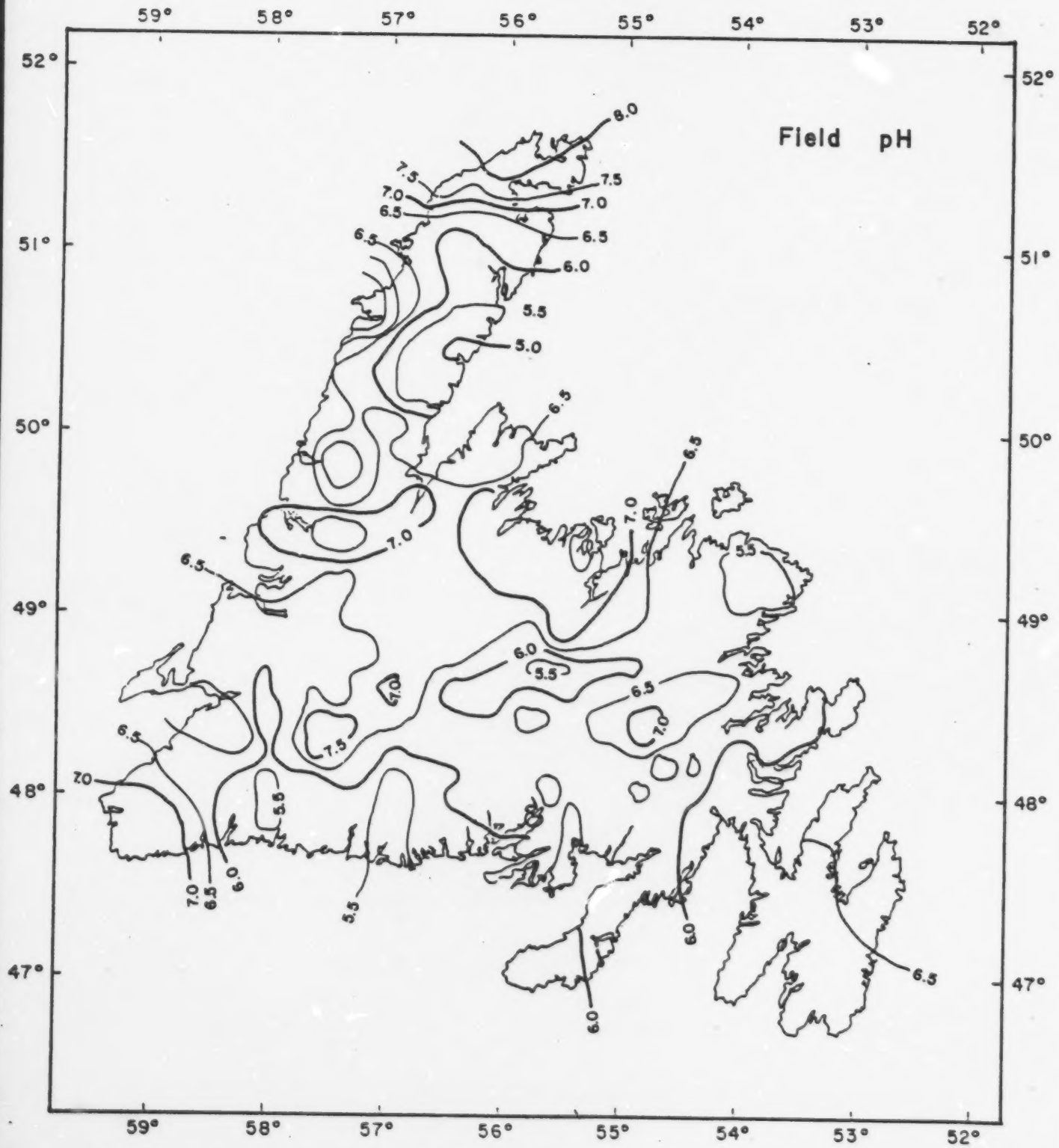

Fig. 22. Spatial distribution of pH (field measured values) in lake water.

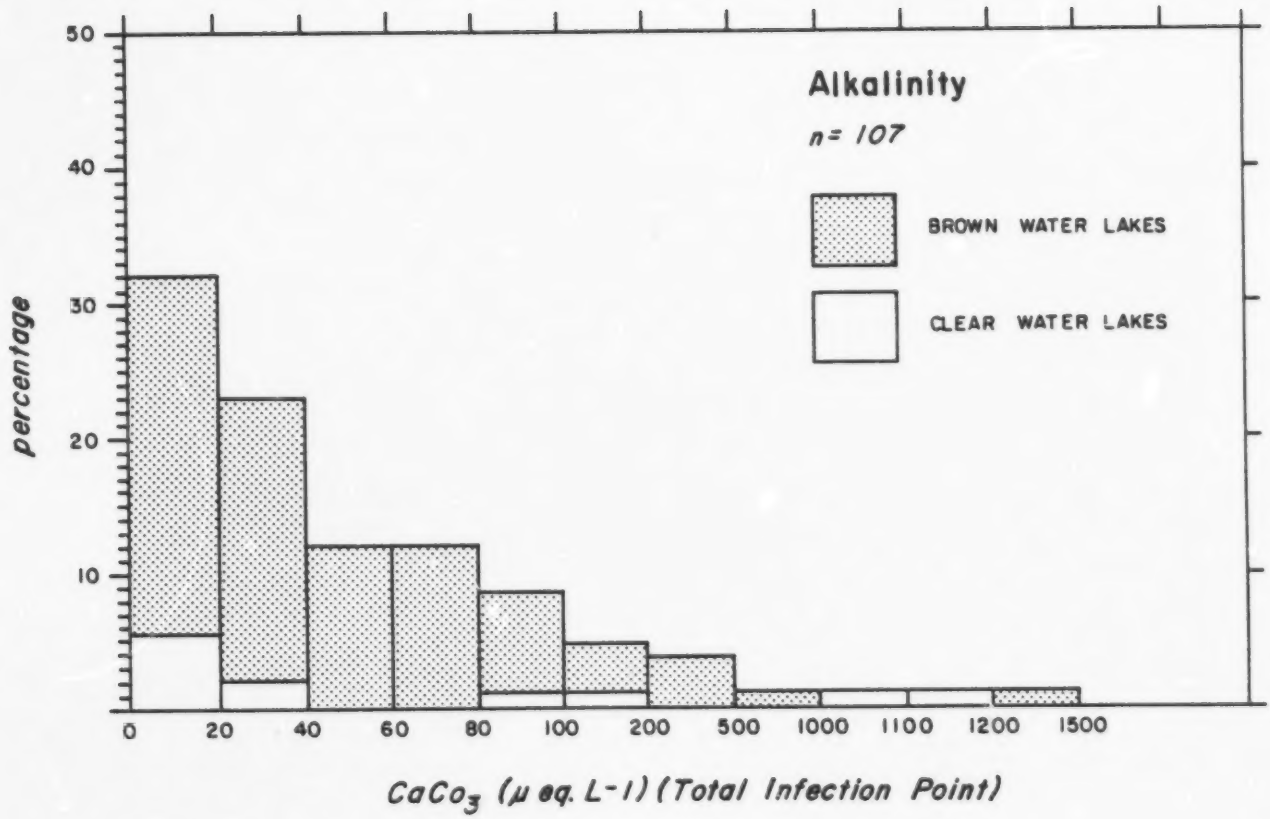

Fig. 23. Distribution of lakes by field alkalinities (TIP values in μ eq L^{-1} $CaCO_3$).

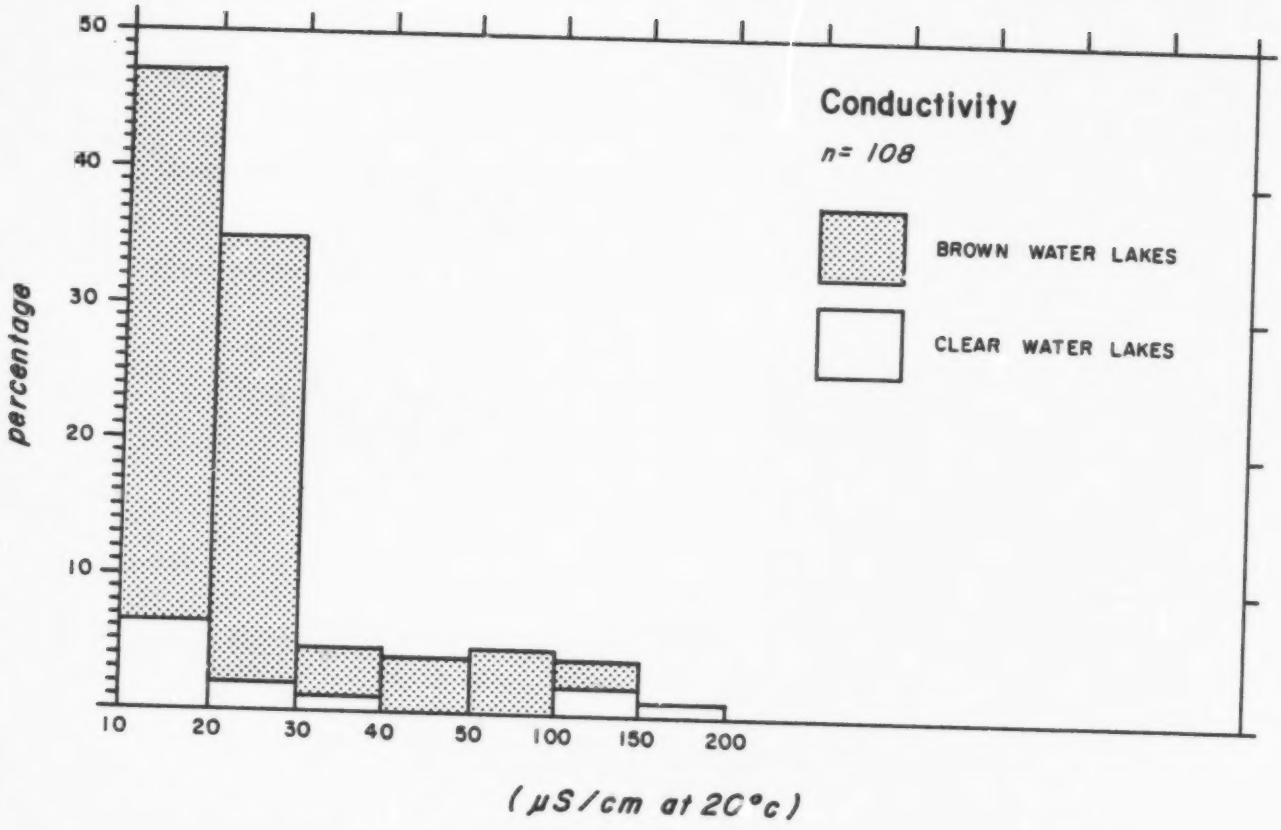

Fig. 24. Distribution of lakes by conductivity (μ S cm^{-1}).

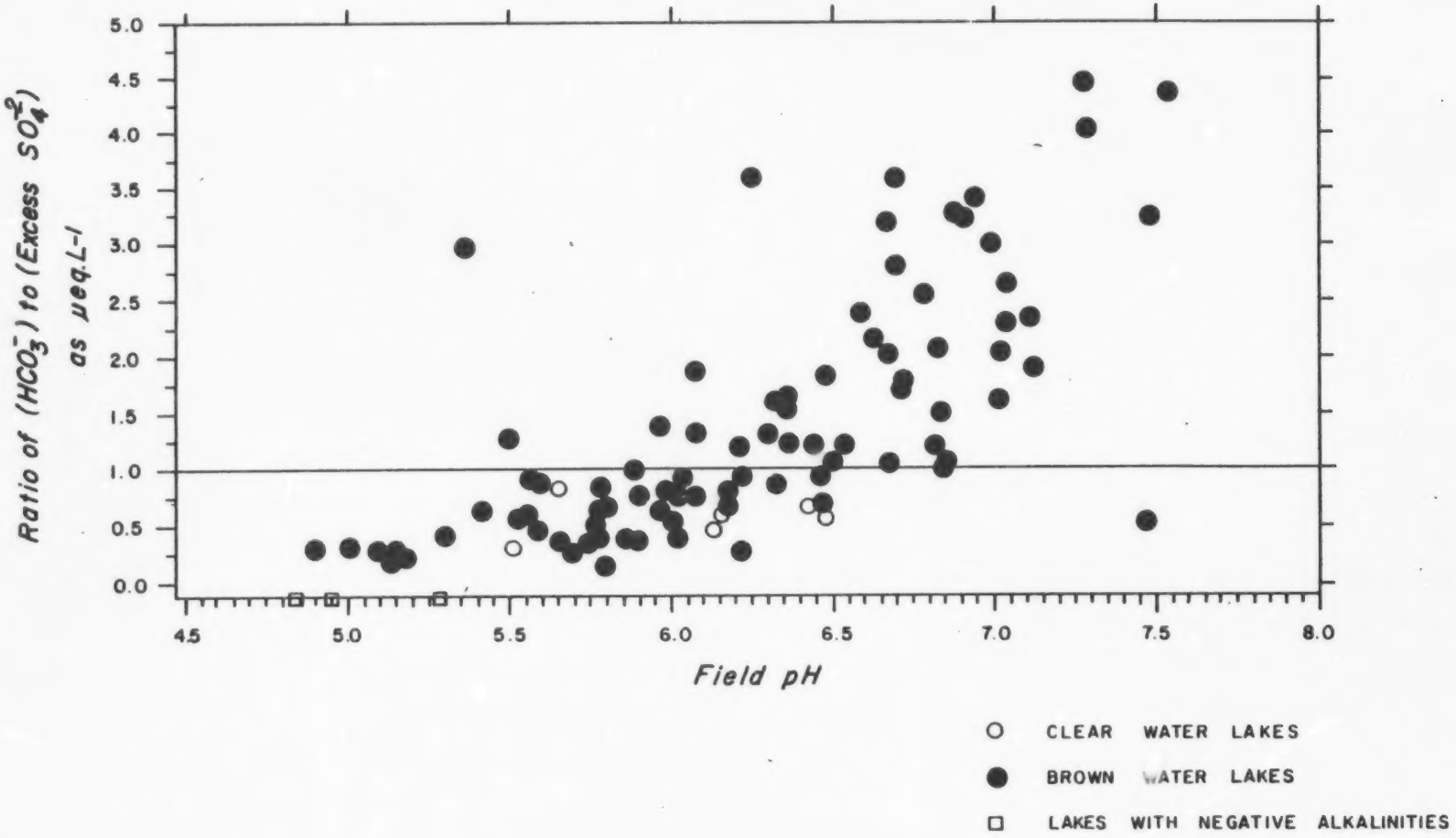

Fig. 25. Ratio of bicarbonate ion to excess sulphate plotted against lake pH.

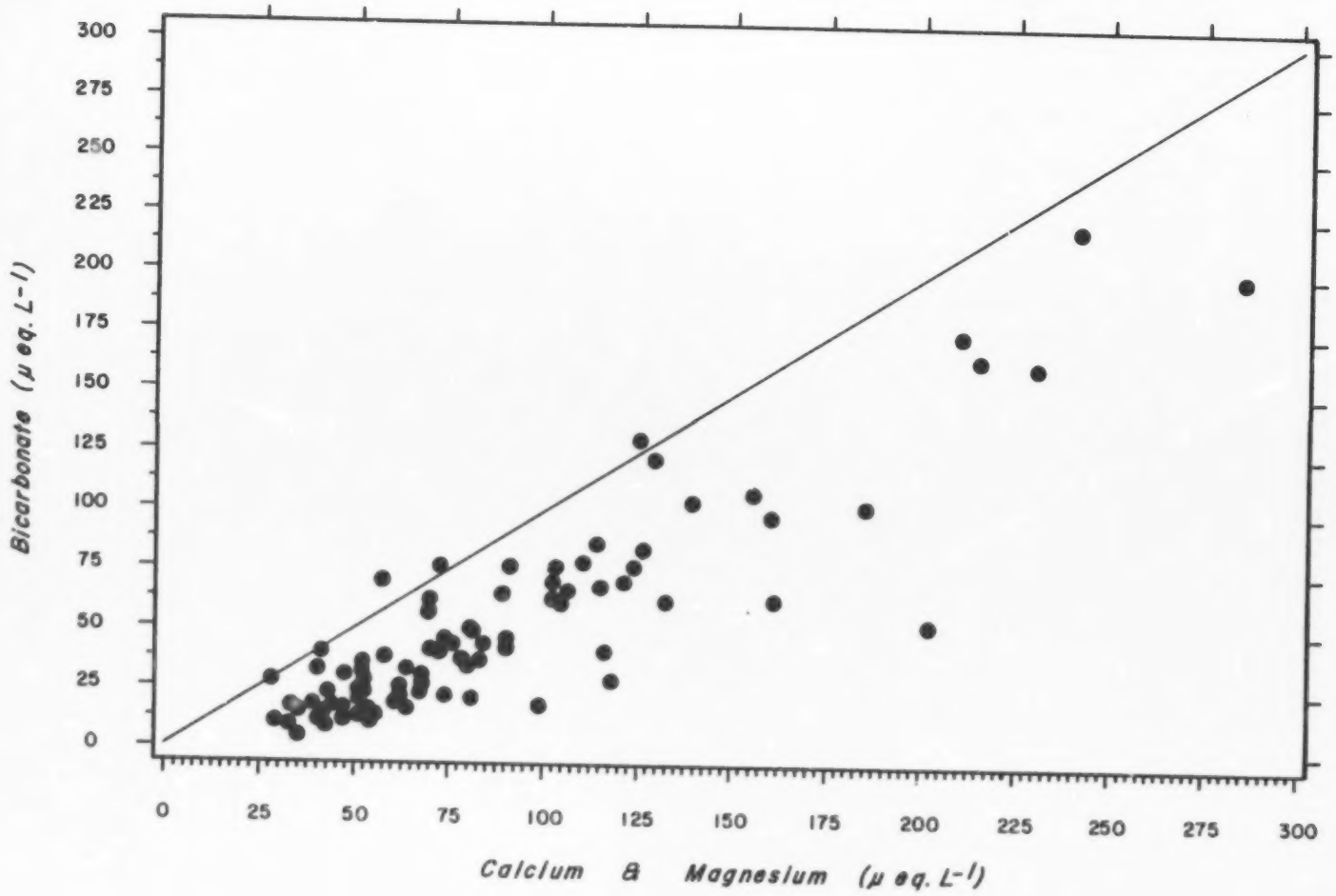

Fig. 26. Sum of non-marine calcium and magnesium ($Ca^{+2}+Mg^{+2}$) plotted against bicarbonate alkalinity.

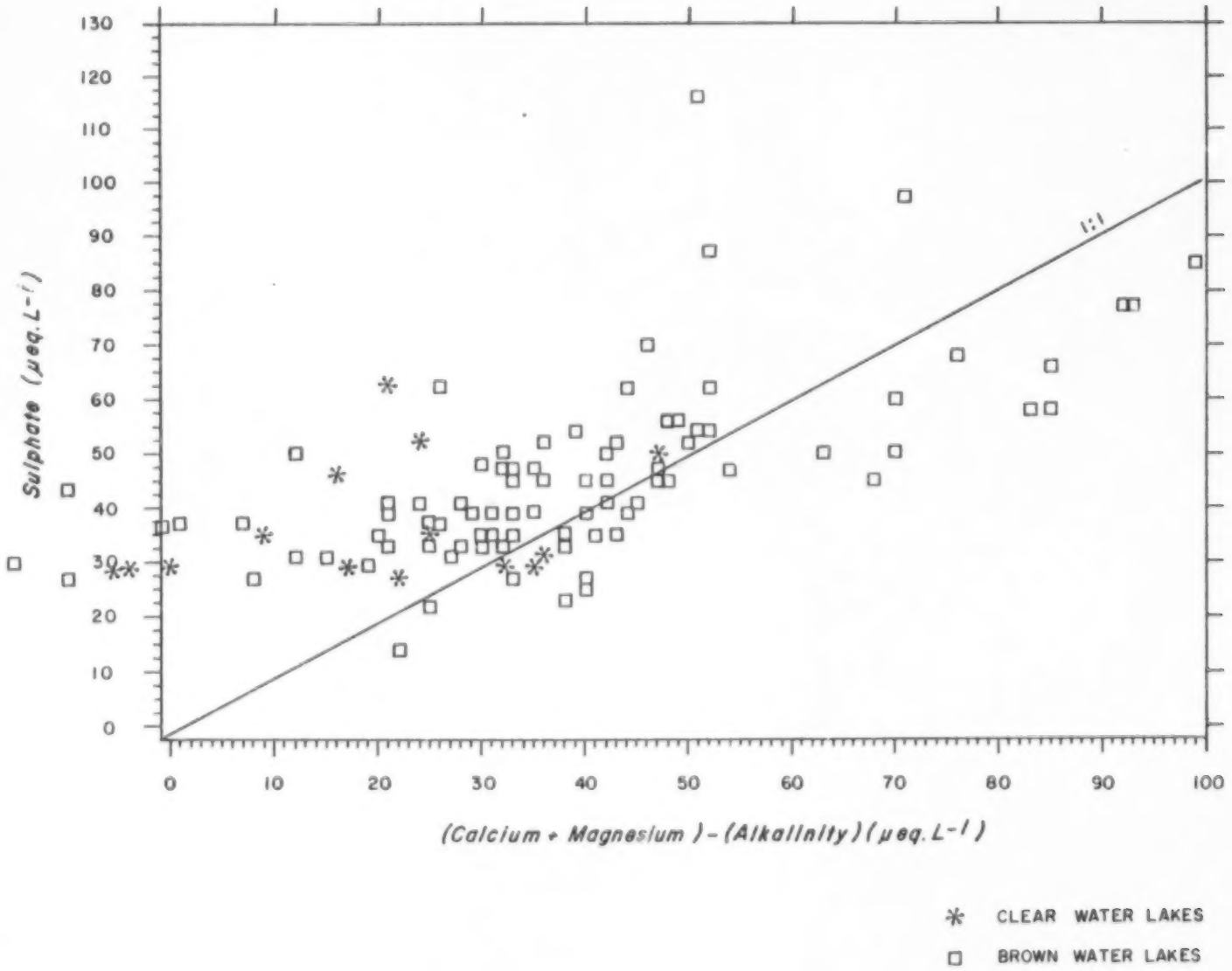

Fig. 27. Sum of non-marine calcium and magnesium minus bicarbonate [$(Ca^{+2}+Mg^{+2})-HCO_3^-$] plotted against non-marine sulphate.

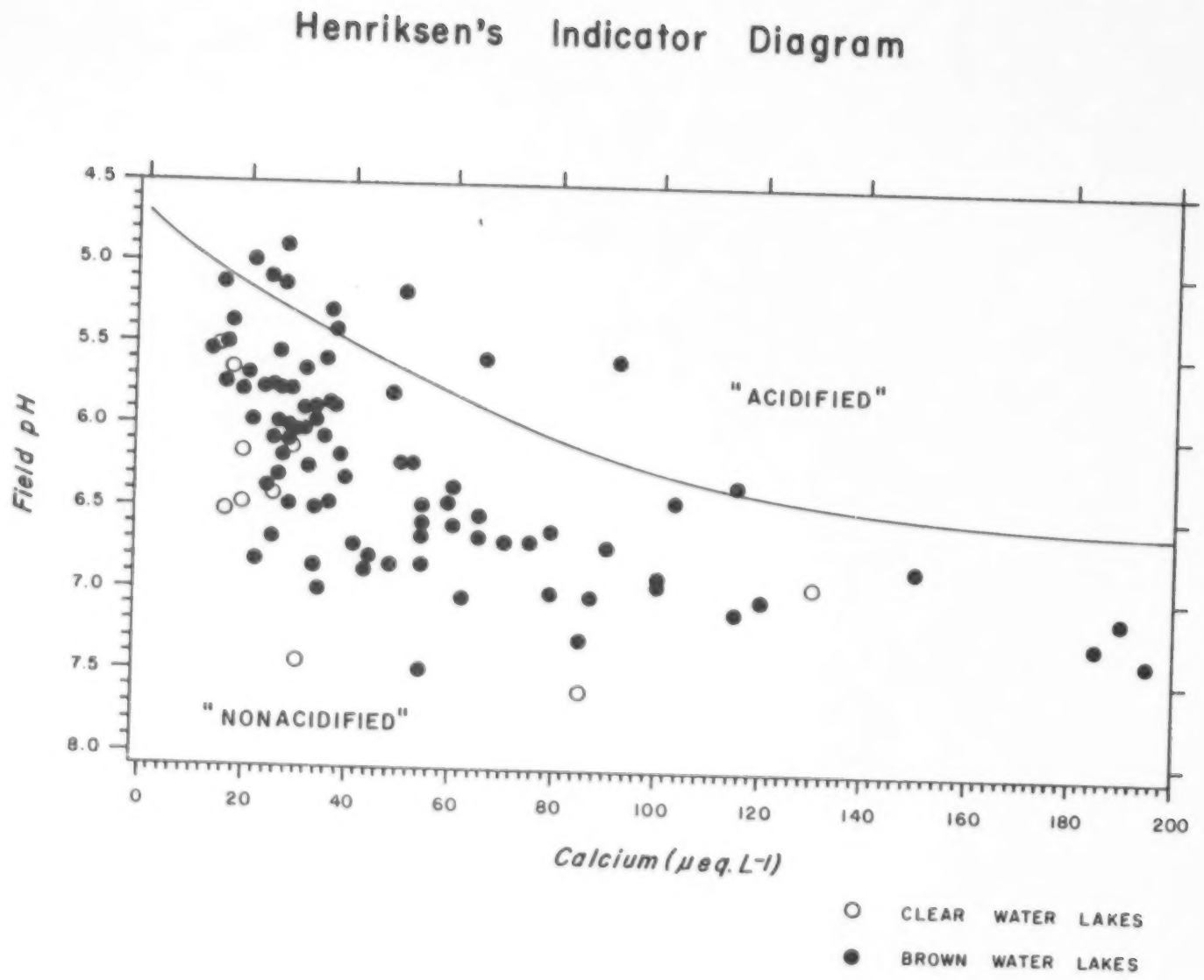

Fig. 28. A plot of study lakes in insular Newfoundland on Henriksen's Indicator Diagram (pH vs. non-marine calcium).

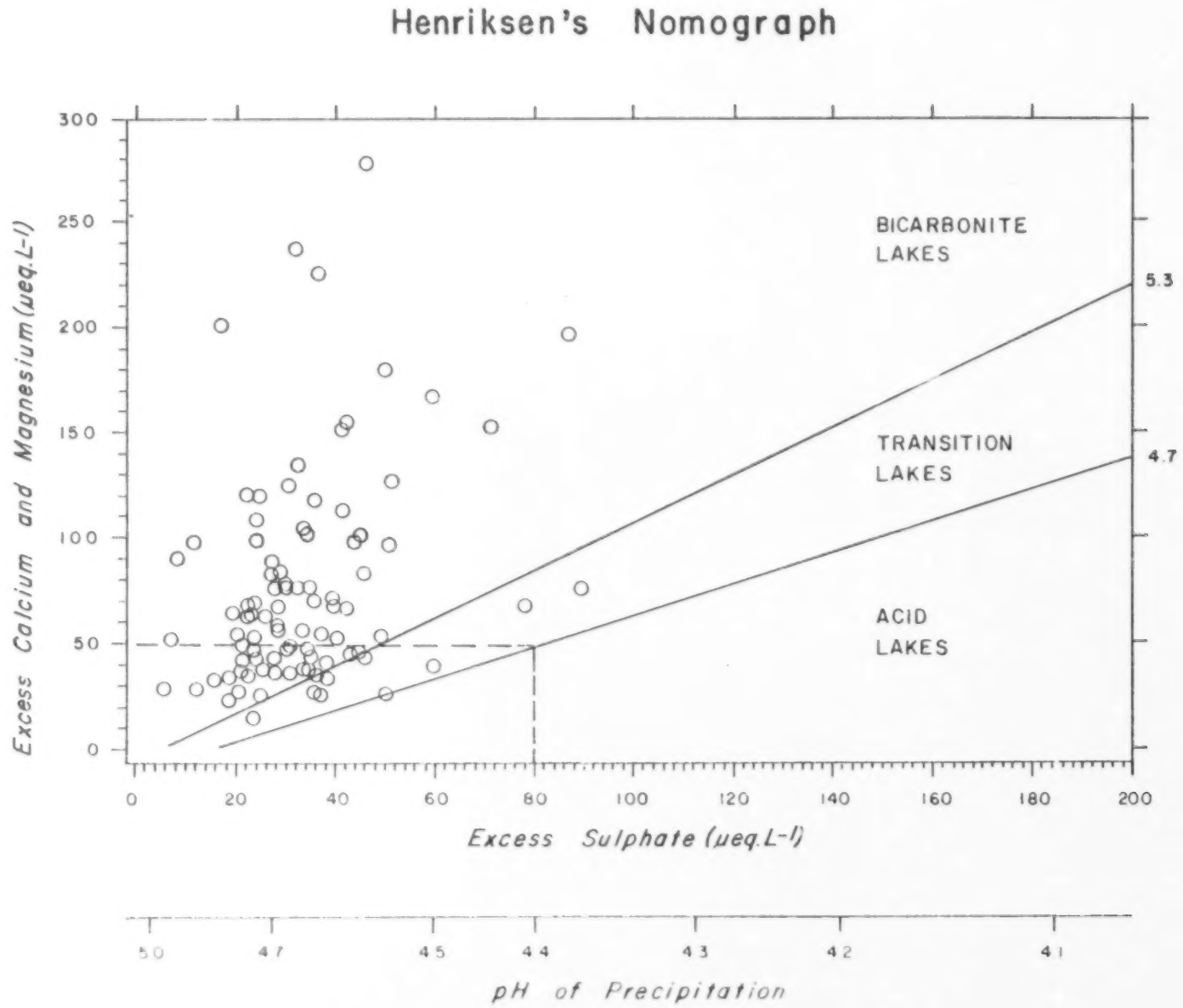

Fig. 29. A plot of study lakes in insular Newfoundland on Henriksen's Nomograph (excess calcium and magnesium vs. excess sulphate or precipitation pH).

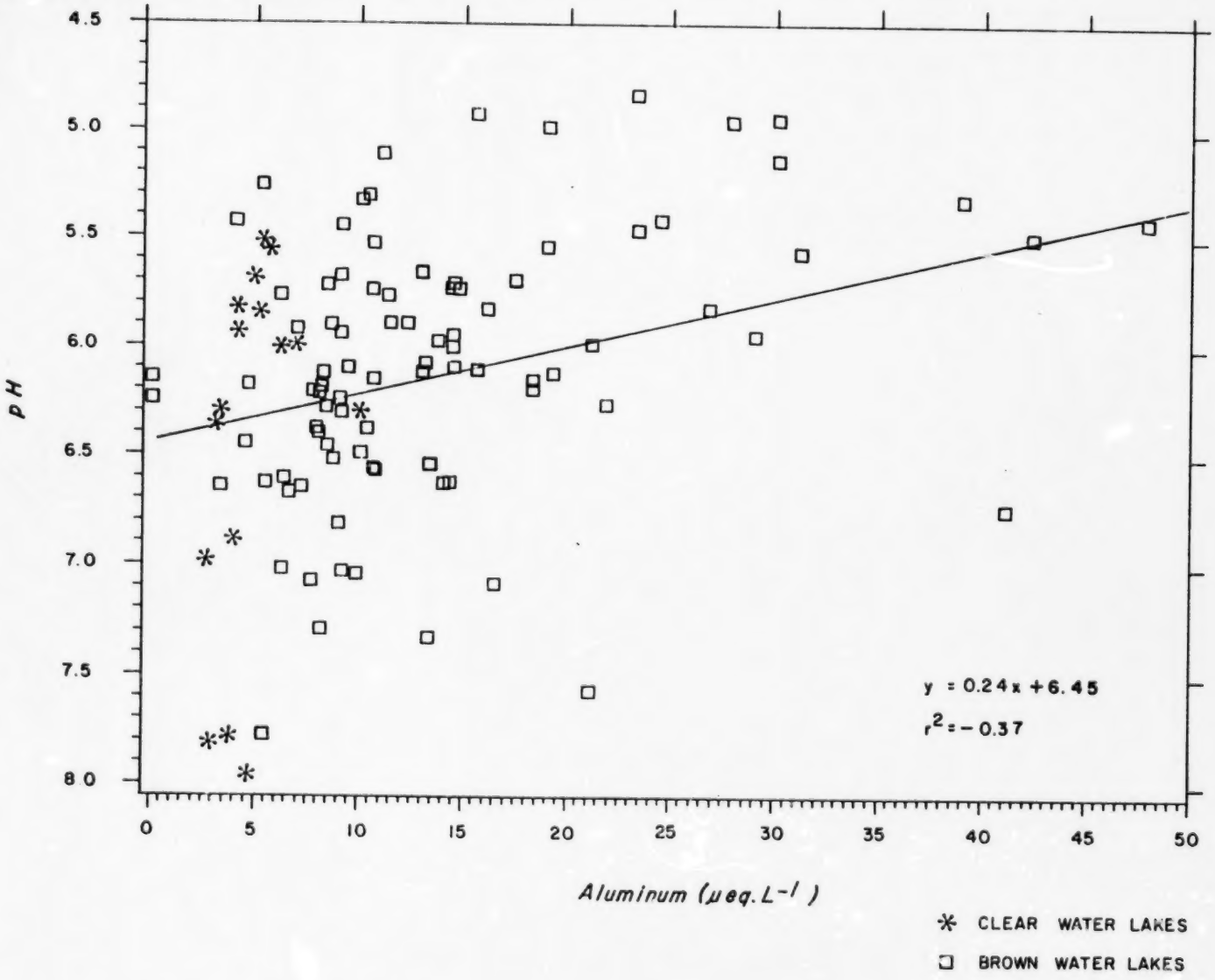

Fig. 30. Total aluminum in lake water (μ eq L^{-1}) vs. pH.

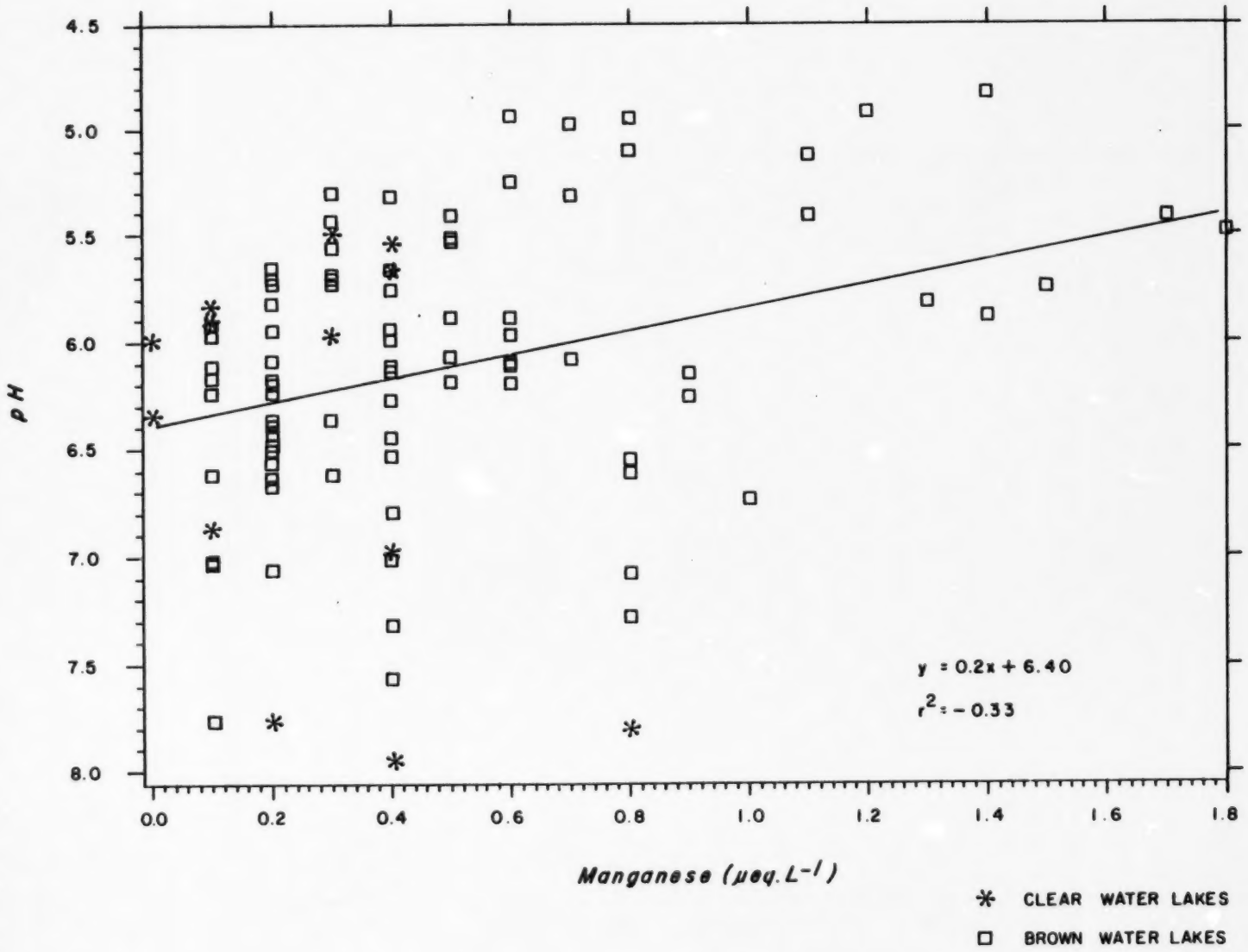

Fig. 31. Total manganese in lake water (μ eq L^{-1}) vs. pH.

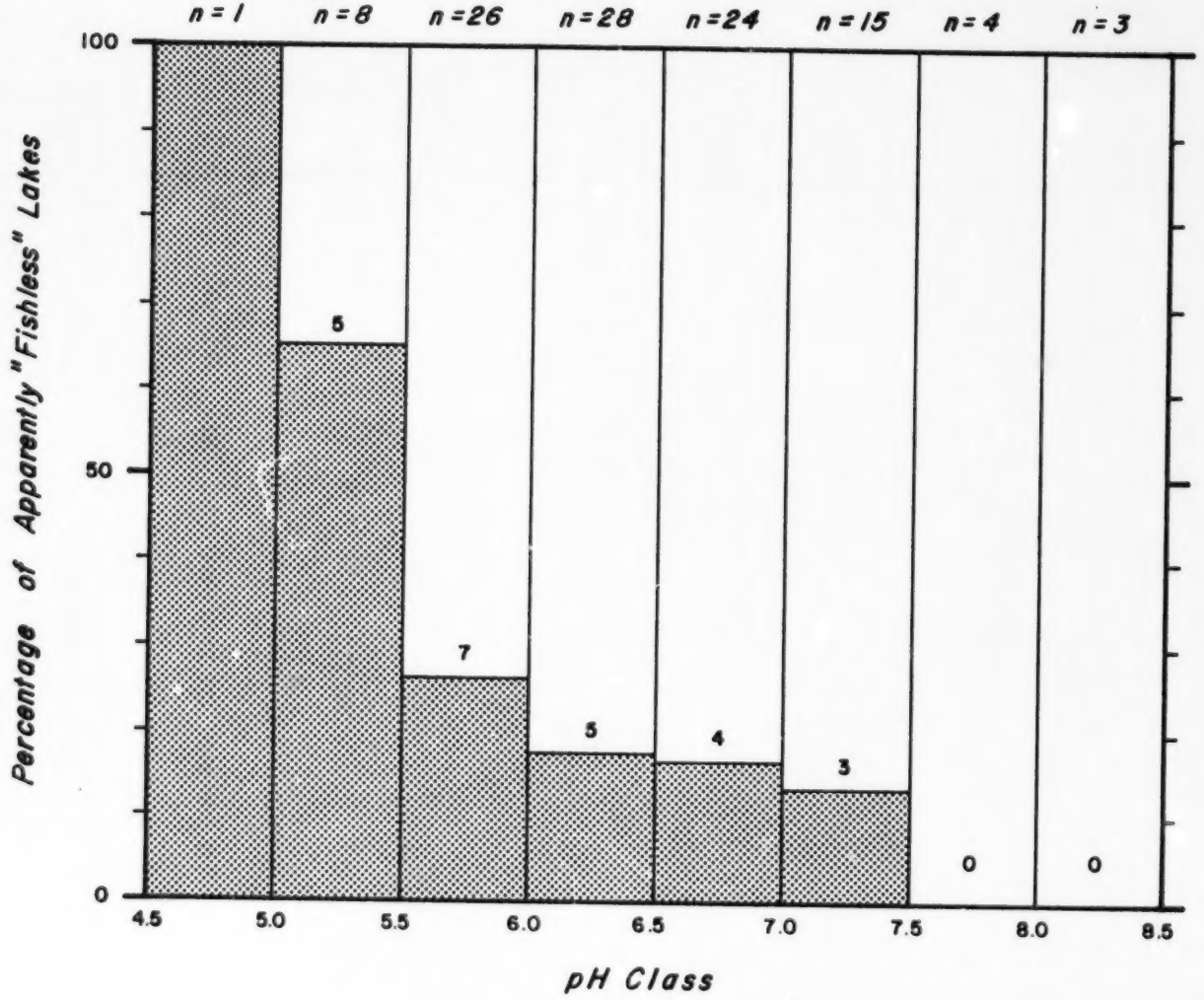

Fig. 32. Percentage of apparently "fishless" lakes vs. pH.

APPENDIX 1: MATRIX OF CORRELATION COEFFICIENTS (LOG VS LOG REGRESSION) LEVEL OF SIGNIFICANCE, AND NUMBER OF OBSERVATIONS FOR 47 PARAMETERS MEASURED IN THE HEADWATER LAKES SURVEY.

CORRELATION COEFFICIENTS / PROB > IRI UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	FLD_PH	LAB_PH	SURFACE	MAX_D	ELEVAT	DIST	DRAIN	RATIO	CO2	DISC	RAIN_PH	FLD_ALK
FLD_PH	1.00000	0.94074	0.03997	-0.18524	-0.30716	0.10630	-0.00702	-0.03580	-0.74331	0.11320		0.86920
	0.0000	0.0001	0.6799	0.6084	0.0012	0.2713	0.9422	0.7117	0.0001	0.2412		0.0001
	109	108	109	10	109	109	109	109	108	109	0	105
LAB_PH	0.94074	1.00000	0.00534	-0.18312	-0.35845	0.01484	-0.01388	-0.00211	-0.75912	0.12643		0.92074
	0.0001	0.0000	0.9563	0.6126	0.0001	0.8788	0.8866	0.9827	0.0001	0.1923		0.0001
	108	108	108	10	108	108	108	108	107	108	0	104
SURFACE	0.03997	0.00534	1.00000	0.48006	-0.04402	0.18018	0.78201	-0.33016	-0.16618	0.30887		-0.12160
LAKE SURFACE AREA	0.6799	0.9563	0.0000	0.1603	0.6495	0.0608	0.0001	0.0005	0.0856	0.0011		0.2166
	109	108	109	10	109	109	109	109	108	109	0	105
MAX D.	-0.18524	-0.18312	0.48006	1.00000	-0.12531	0.17069	0.52929	-0.41459	-0.06124	0.45727		-0.23962
MAXTMUM DEPTH	0.6084	0.6126	0.1603	0.0000	0.7302	0.6373	0.1157	0.2336	0.8665	0.1839		0.5049
	10	10	10	10	10	10	10	10	10	10	0	10
ELEVAT	-0.30716	-0.35845	-0.04402	-0.12531	1.00000	0.47245	-0.14682	-0.14581	0.11577	0.21235		-0.39293
	0.0012	0.0001	0.6495	0.7302	0.0000	0.0001	0.1277	0.1303	0.2328	0.0266		0.0001
	109	108	109	10	109	109	109	109	108	109	0	105
DIST	0.10630	0.01484	0.18018	0.17069	0.47245	1.00000	0.12006	-0.10519	-0.02514	-0.04634		-0.00825
DISTANCE FROM COAST	0.2713	0.8788	0.0608	0.6373	0.0001	0.0000	0.2137	0.2763	0.7962	0.6323		0.9335
	109	108	109	10	109	109	109	109	108	109	0	105
DRAIN	-0.00702	-0.01388	0.78201	0.52929	-0.14682	0.12006	1.00000	0.22774	0.01846	0.07183		-0.04928
DRAINAGE AREA	0.9422	0.8866	0.0001	0.1157	0.1277	0.2137	0.0000	0.0172	0.8496	0.4580		0.6176
	109	108	109	10	109	109	109	109	108	109	0	105
RATIO	-0.03580	-0.00211	-0.33016	-0.41459	-0.14581	-0.10519	0.22774	1.00000	0.27038	-0.37996		0.14614
DRAINAGE/LAKE AREA	0.7117	0.9827	0.0005	0.2336	0.1303	0.2763	0.0172	0.0000	0.0047	0.0001		0.1369
	109	108	109	10	109	109	109	109	108	109	0	105
CO2	-0.74331	-0.75912	-0.16618	-0.06124	0.11577	-0.02514	0.01846	0.27038	1.00000	-0.39513		-0.56871
	0.0001	0.0001	0.0856	0.8665	0.2328	0.7962	0.8496	0.0047	0.0000	0.0001		0.0001
	108	107	108	10	108	108	108	108	108	108	0	105
DISC	0.11320	0.12643	0.30887	0.45727	0.21235	-0.04634	0.07183	-0.37996	-0.39513	1.00000		-0.08997
SECCHI DISC READING	0.2412	0.1923	0.0011	0.1839	0.0266	0.6323	0.4580	0.0001	0.0001	0.0000		0.3614
	109	108	109	10	109	109	109	109	108	109	0	105

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APPENDIX 1 (Cont'd.)

CORRELATION COEFFICIENTS / PROB > IRI UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	FLD_PH	LAB_PH	SURFACE	MAX_D	ELEVAT	DIST	DRAIN	RATIO	CO2	DISC	RAIN_PH	FLD_ALK
RAIN_PH												
	0	0	0	0	0	0	0	0	0	0	0	0
FLD_ALK	0.86920	0.92074	-0.12160	-0.23962	-0.39293	-0.00825	-0.04928	0.14614	-0.56871	-0.08997		1.00000
	0.0001	0.0001	0.2166	0.5049	0.0001	0.9335	0.6176	0.1369	0.0001	0.3614		0.0000
	105	104	105	10	105	105	105	105	105	105	0	105
LAB_ALK	0.87751	0.91674	-0.06984	-0.40604	-0.42452	0.00111	-0.03163	0.08431	-0.59588	-0.07536		0.95216
	0.0001	0.0001	0.4790	0.2443	0.0001	0.9910	0.7488	0.3925	0.0001	0.4448		0.0001
	105	105	105	10	105	105	105	105	104	105	0	103
COND	0.55197	0.65059	-0.20700	-0.20127	-0.63337	-0.41084	-0.16325	0.08694	-0.38155	-0.12992		0.71000
CONDUCTIVITY	0.0001	0.0001	0.0316	0.5771	0.0001	0.0001	0.0914	0.3710	0.0001	0.1802		0.0001
	108	108	108	10	108	108	108	108	107	108	0	104
TDS	0.56310	0.66192	-0.20796	-0.17297	-0.61881	-0.39917	-0.17104	0.06986	-0.41094	-0.11367		0.71248
	0.0001	0.0001	0.0308	0.6327	0.0001	0.0001	0.0768	0.4725	0.0001	0.2414		0.0001
	108	108	108	10	108	108	108	108	107	108	0	104
HARD	0.71144	0.79553	-0.16765	-0.30681	-0.58673	-0.21043	-0.11690	0.11602	-0.46065	-0.17035		0.86219
TOTAL HARDNESS	0.0001	0.0001	0.0814	0.3885	0.0001	0.0281	0.2260	0.2296	0.0001	0.0766		0.0001
	109	108	109	10	109	109	109	109	108	109	0	105
CAR												
CARBONATE												
	0	0	0	0	0	0	0	0	0	0	0	0
BICAR	0.83826	0.88779	-0.03009	-0.56308	-0.43103	0.00510	0.01948	0.10019	-0.56589	-0.11742		0.91564
BICARBONATE	0.0001	0.0001	0.7572	0.0901	0.0001	0.9582	0.8414	0.3022	0.0001	0.2262		0.0001
	108	108	108	10	108	108	108	108	107	108	0	104
CA	0.77818	0.84503	-0.16972	-0.33641	-0.48465	-0.10694	-0.11487	0.13617	-0.48166	-0.16500		0.90234
	0.0001	0.0001	0.0777	0.3419	0.0001	0.2684	0.2343	0.1580	0.0001	0.0864		0.0001
	109	108	109	10	109	109	109	109	108	109	0	105
MG	0.56123	0.66434	-0.13805	-0.20989	-0.65345	-0.30397	-0.10044	0.06863	-0.40199	-0.15615		0.72034
	0.0001	0.0001	0.1523	0.5606	0.0001	0.0013	0.2987	0.4783	0.0001	0.1049		0.0001
	109	108	109	10	109	109	109	109	108	109	0	105

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APPENDIX 1 (Cont'd.)

CORRELATION COEFFICIENTS / PROB > IRI UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	FLD_PH	LAB_PH	SURFACE	MAX_D	ELEVAT	DIST	DRAIN	RATIO	CO2	DISC	RAIN_PH	FLD_ALK
NA	0.17928	0.27354	-0.13147	0.09722	-0.67527	-0.58985	-0.06360	0.11824	-0.12224	-0.14761		0.33782
	0.0621	0.0042	0.1730	0.7893	0.0001	0.0001	0.5112	0.2208	0.2075	0.1256		0.0004
	109	108	109	10	109	109	109	109	108	109	0	105
K	0.30711	0.38489	-0.08414	0.01905	-0.47672	-0.15021	0.02298	0.18824	-0.10547	-0.23187		0.46764
	0.0012	0.0001	0.3844	0.9583	0.0001	0.1190	0.8125	0.0500	0.2773	0.0153		0.0001
	109	108	109	10	109	109	109	109	108	109	0	105
CL	0.07078	0.14973	-0.14087	0.23407	-0.63639	-0.60118	-0.10814	0.04751	-0.05116	-0.14484		0.25117
	0.4667	0.1219	0.1459	0.5151	0.0001	0.0001	0.2653	0.6254	0.6008	0.1348		0.0101
	108	108	108	10	108	108	108	108	107	108	0	104
SO4	0.04467	0.11661	-0.46213	-0.04317	-0.27146	-0.30216	-0.34067	0.22934	0.17927	-0.37879		0.32307
	0.6462	0.2294	0.0001	0.9057	0.0045	0.0015	0.0003	0.0170	0.0647	0.0001		0.0008
	108	108	108	10	108	108	108	108	107	108	0	104
EX_SO4	0.02863	0.08218	-0.44888	-0.07334	-0.01422	-0.08060	-0.34291	0.21221	0.20085	-0.33683		0.26297
	0.7687	0.3978	0.0001	0.8404	0.8839	0.4070	0.0003	0.0275	0.0380	0.0004		0.0070
	108	108	108	10	108	108	108	108	107	108	0	104
PO4	0.09877	0.07454	0.03427	0.29424	0.05864	0.02593	-0.12610	-0.17812	-0.17282	0.16736		0.02918
	0.3092	0.4433	0.7248	0.4092	0.5466	0.7899	0.1935	0.0651	0.0751	0.0834		0.7687
	108	108	108	10	108	108	108	108	107	108	0	104
NO3	-0.21814	-0.16624	0.06529	0.71692	0.17190	-0.11953	0.02537	-0.08095	-0.02135	0.32797		-0.18823
	0.0233	0.0855	0.5020	0.0196	0.0752	0.2179	0.7944	0.4050	0.8272	0.0005		0.0557
	108	108	108	10	108	108	108	108	107	108	0	104
CATION	0.61843	0.71718	-0.18088	-0.25660	-0.65069	-0.35528	-0.12731	0.11582	-0.41341	-0.15290		0.77493
SUM OF CATIONS	0.0001	0.0001	0.0598	0.4742	0.0001	0.0002	0.1871	0.2304	0.0001	0.1124		0.0001
	109	108	109	10	109	109	109	109	108	109	0	105
ANION	0.61760	0.70429	-0.19259	-0.39904	-0.64161	-0.34783	-0.14559	0.09417	-0.41935	-0.15220		0.77608
SUM OF ANIONS	0.0001	0.0001	0.0458	0.2533	0.0001	0.0002	0.1327	0.3323	0.0001	0.1158		0.0001
	108	108	108	10	108	108	108	108	107	108	0	104
CONST	0.57948	0.67530	-0.21096	-0.33314	-0.63592	-0.32535	-0.16545	0.10788	-0.39263	-0.14502		0.73379
SUM OF CONSTITUENTS	0.0001	0.0001	0.0277	0.3469	0.0001	0.0006	0.0856	0.2642	0.0001	0.1324		0.0001
	109	108	109	10	109	109	109	109	108	109	0	105

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APPENDIX 1 (Cont'd.)

CORRELATION COEFFICIENTS / PROB ùRù UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	FLD_PH	LAB_PH	SURFACE	MAX_D	ELEVAT	DIST	DRAIN	RATIO	CO2	DISC	RAIN_PH	FLD_ALK
TURBID	-0.28553	-0.30118	-0.27870	-0.44830	-0.16657	-0.07607	-0.15463	0.19177	0.37618	-0.61692		-0.10339
TURBIDITY	0.0027	0.0015	0.0035	0.1938	0.0849	0.4339	0.1101	0.0468	0.0001	0.0001		0.2963
	108	108	108	10	108	108	108	108	107	108	0	104
COLOR	-0.34858	-0.33873	-0.24239	-0.17359	-0.11953	-0.06736	0.02995	0.43019	0.60956	-0.65767		-0.00654
	0.0002	0.0003	0.0115	0.6315	0.2179	0.4885	0.7583	0.0001	0.0001	0.0001		0.9474
	108	108	108	10	108	108	108	108	107	108	0	104
PB	0.00000	0.00000	0.00000		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000		0.00000
	1	1	1	0	1	1	1	1	1	1	0	1
AL	-0.42895	-0.41503	-0.30692	0.02861	-0.18341	-0.21633	-0.08351	0.35948	0.57532	-0.44917		-0.15186
	0.0001	0.0001	0.0013	0.9418	0.0586	0.0252	0.3924	0.0001	0.0001	0.0001		0.1257
	107	106	107	9	107	107	107	107	106	107	0	103
MN	-0.33324	-0.32847	-0.23411	-0.25004	-0.26396	-0.23207	-0.06652	0.27978	0.43254	-0.35883		-0.16770
	0.0005	0.0006	0.0152	0.4860	0.0060	0.0162	0.4961	0.0035	0.0001	0.0001		0.0904
	107	106	107	10	107	107	107	107	106	107	0	103
CD	-0.11039	-0.10515	0.03753	0.00000	0.11593	-0.02117	-0.00115	-0.08712	0.02054	0.13241		-0.15096
	0.2532	0.2788	0.6985	1.0000	0.2300	0.8270	0.9905	0.3677	0.8329	0.1699		0.1242
	109	108	109	10	109	109	109	109	108	109	0	105
FE	-0.23576	-0.26689	-0.17840	0.59893	-0.16961	0.08396	0.01080	0.33032	0.40894	-0.55561		-0.09061
	0.0140	0.0055	0.0647	0.0673	0.0793	0.3876	0.9116	0.0005	0.0001	0.0001		0.3603
	108	107	108	10	108	108	108	108	107	108	0	104
CU	0.19927	0.24882	0.15715	0.18009	-0.28951	-0.09474	-0.01597	-0.27482	-0.45013	0.21638		0.21598
	0.4279	0.3194	0.5334	0.8199	0.2439	0.7085	0.9498	0.2697	0.0609	0.3885		0.4051
	18	18	18	4	18	18	18	18	18	18	0	17
ZN	0.34637	0.43505	-0.26778	0.00000	0.21003	0.09502	-0.26340	-0.04748	-0.17260	0.21964		0.47091
	0.1591	0.0712	0.2827	1.0000	0.4029	0.7076	0.2909	0.8516	0.4934	0.3812		0.0564
	18	18	18	4	18	18	18	18	18	18	0	17
NI	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000		0.00000
	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000		1.0000
	18	18	18	4	18	18	18	18	18	18	0	17

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APPENDIX 1 (Cont'd.)

CORRELATION COEFFICIENTS / PROB > IRI UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	FLD_PH	LAB_PH	SURFACE	MAX_D	ELEVAT	DIST	DRAIN	RATIO	CO2	DISC	RAIN_PH	FLD_ALK
SED	0.67994	0.64822	0.15074	-0.22868	-0.20851	0.19884	0.15773	0.02903	-0.55354	0.09816		0.64291
SEDIMENT PH	0.0001	0.0001	0.1820	0.6630	0.0634	0.0770	0.1623	0.7983	0.0001	0.3863		0.0001
	80	79	80	6	80	80	80	80	80	80	0	77
EX_NA	0.37497	0.43778	-0.08085	-0.07583	-0.60902	-0.46015	0.03153	0.21751	-0.25939	-0.14206		0.48017
	0.0001	0.0001	0.4055	0.8351	0.0001	0.0001	0.7460	0.0237	0.0070	0.1425		0.0001
	108	108	108	10	108	108	108	108	107	108	0	104
EX_K	0.38178	0.43747	-0.07477	0.27068	0.02801	0.11139	-0.04595	0.08833	-0.32916	0.10767		0.39381
	0.0003	0.0001	0.4991	0.5167	0.8004	0.3131	0.6781	0.4243	0.0022	0.3296		0.0002
	84	84	84	8	84	84	84	84	84	84	0	83
EX_CA	0.78257	0.84905	-0.16748	-0.33753	-0.48897	-0.10476	-0.11184	0.13678	-0.48167	-0.15800		0.90477
	0.0001	0.0001	0.0832	0.3402	0.0001	0.2806	0.2492	0.1581	0.0001	0.1024		0.0001
	108	108	108	10	108	108	108	108	107	108	0	104
EX_MG	0.59154	0.68248	-0.12188	-0.23863	-0.62519	-0.23858	-0.08676	0.06718	-0.42089	-0.16112		0.74434
	0.0001	0.0001	0.2089	0.5067	0.0001	0.0129	0.3719	0.4897	0.0001	0.0958		0.0001
	108	108	108	10	108	108	108	108	107	108	0	104
DOC	-0.34319	-0.34119	-0.28095	-0.12612	-0.18231	-0.09990	0.00595	0.46194	0.61871	-0.68703		-0.01908
	0.0003	0.0003	0.0032	0.7285	0.0590	0.3036	0.9513	0.0001	0.0001	0.0001		0.8475
	108	108	108	10	108	108	108	108	107	108	0	104
GEOL WT	-0.55218	-0.58215	0.11002	-0.04597	0.41045	0.24994	0.08056	0.00628	0.46960	0.01269		-0.58793
WEIGHTED GEOLOGY	0.0001	0.0001	0.2859	0.9139	0.0001	0.0141	0.4353	0.9516	0.0001	0.9024		0.0001
	96	95	96	8	96	96	96	96	95	96	0	92

	LAB_ALK	COND	TDS	HARD	CAR	BICAR	CA	MG	NA	K	CL	SO4
FLD_PH	0.87751	0.55197	0.56310	0.71144		0.83826	0.77818	0.56123	0.17928	0.30711	0.07078	0.04467
	0.0001	0.0001	0.0001	0.0001		0.0001	0.0001	0.0001	0.0621	0.0012	0.4667	0.6462
	105	108	108	109	0	108	109	109	109	109	108	108
LAB_PH	0.91674	0.65059	0.66192	0.79553		0.88779	0.84503	0.66434	0.27354	0.38489	0.14973	0.11661
	0.0001	0.0001	0.0001	0.0001		0.0001	0.0001	0.0001	0.0042	0.0001	0.1219	0.2294
	105	108	108	108	0	108	108	108	108	108	108	108

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APPENDIX 1 (Cont'd.)

CORRELATION COEFFICIENTS / PROB > IRI UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	LAB_ALK	COND	TDS	HARD	CAR	BICAR	CA	MG	NA	K	CL	SO4
SURFACE	-0.06984	-0.20700	-0.20796	-0.16765		-0.03009	-0.16972	-0.13805	-0.13147	-0.08414	-0.14087	-0.46213
LAKE SURFACE AREA	0.4790	0.0316	0.0308	0.0814		0.7572	0.0777	0.1523	0.1730	0.3844	0.1459	0.0001
	105	108	108	109	0	108	109	109	109	109	108	108
MAX D	-0.40604	-0.20127	-0.17297	-0.30681		-0.56308	-0.33641	-0.20989	0.09722	0.01905	0.23407	-0.04317
MAXIMUM DEPTH	0.2443	0.5771	0.6327	0.3885		0.0901	0.3419	0.5606	0.7893	0.9583	0.5151	0.9057
	10	10	10	10	0	10	10	10	10	10	10	10
ELEVAT	-0.42452	-0.63337	-0.61881	-0.58673		-0.43103	-0.48465	-0.65345	-0.67527	-0.47672	-0.63639	-0.27146
	0.0001	0.0001	0.0001	0.0001		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0045
	105	108	108	109	0	108	109	109	109	109	108	108
DIST	0.00111	-0.41084	-0.39917	-0.21043		0.00510	-0.10694	-0.30397	-0.58985	-0.15021	-0.60118	-0.30216
DISTANCE FROM COAST	0.9910	0.0001	0.0001	0.0281		0.9582	0.2684	0.0013	0.0001	0.1190	0.0001	0.0015
	105	108	108	109	0	108	109	109	109	109	108	108
DRAIN	-0.03163	-0.16325	-0.17104	-0.11690		0.01948	-0.11487	-0.10044	-0.06360	0.02298	-0.10814	-0.34067
DRAINAGE AREA	0.7488	0.0914	0.0768	0.2260		0.8414	0.2343	0.2987	0.5112	0.8125	0.2653	0.0003
	105	108	108	109	0	108	109	109	109	109	108	108
RATIO	0.08431	0.08694	0.06986	0.11602		0.10019	0.13617	0.06863	0.11824	0.18824	0.04751	0.22934
DRAINAGE/LAKE AREA	0.3925	0.3710	0.4725	0.2296		0.3022	0.1580	0.4783	0.2208	0.0500	0.6254	0.0170
	105	108	108	109	0	108	109	109	109	109	108	108
CO2	-0.59588	-0.38155	-0.41094	-0.46065		-0.56589	-0.48166	-0.40199	-0.12224	-0.10547	-0.05116	0.17927
	0.0001	0.0001	0.0001	0.0001		0.0001	0.0001	0.0001	0.2075	0.2773	0.6008	0.0647
	104	107	107	108	0	107	108	108	108	108	107	107
DISC	-0.07536	-0.12992	-0.11367	-0.17035		-0.11742	-0.16500	-0.15615	-0.14761	-0.23187	-0.14484	-0.37879
SECCHI DISC READING	0.4448	0.1802	0.2414	0.0766		0.2262	0.0864	0.1049	0.1256	0.0153	0.1348	0.0001
	105	108	108	109	0	108	109	109	109	109	108	108
RAIN_PH												
	0	0	0	0	0	0	0	0	0	0	0	0
FLD_ALK	0.95216	0.71000	0.71248	0.86219		0.91564	0.90234	0.72034	0.33782	0.46764	0.25117	0.32307
	0.0001	0.0001	0.0001	0.0001		0.0001	0.0001	0.0001	0.0004	0.0001	0.0101	0.0008
	103	104	104	105	0	104	105	105	105	105	104	104

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APPENDIX 1 (Cont'd.)

CORRELATION COEFFICIENTS / PROB > IRI UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	LAB_ALK	COND	TDS	HARD	CAR	BICAR	CA	MG	NA	K	CL	SO4
LAB_ALK	1.00000	0.70561	0.71012	0.85746		0.94943	0.88344	0.74515	0.32971	0.44661	0.23173	0.20564
	0.0000	0.0001	0.0001	0.0001		0.0001	0.0001	0.0001	0.0006	0.0001	0.0174	0.0353
	105	105	105	105	0	105	105	105	105	105	105	105
COND CONDUCTIVITY	0.70561	1.00000	0.99690	0.93530		0.73623	0.86315	0.93020	0.77551	0.51302	0.73954	0.55992
	0.0001	0.0000	0.0001	0.0001		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	105	108	108	108	0	108	108	108	108	108	108	108
TDS	0.71012	0.99690	1.00000	0.93448		0.73817	0.86336	0.93002	0.74886	0.49319	0.71372	0.54157
	0.0001	0.0001	0.0000	0.0001		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	105	108	108	108	0	108	108	108	108	108	108	108
HARD TOTAL HARDNESS	0.85746	0.93530	0.93448	1.00000		0.88295	0.96331	0.94110	0.57320	0.49728	0.52829	0.49127
	0.0001	0.0001	0.0001	0.0000		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	105	108	108	109	0	108	109	109	109	109	108	108
CAR CARBONATE												
	0	0	0	0	0	0	0	0	0	0	0	0
BICAR BICARBONATE	0.94943	0.73623	0.73817	0.88295		1.00000	0.90132	0.77986	0.35345	0.43643	0.24866	0.25200
	0.0001	0.0001	0.0001	0.0001		0.0000	0.0001	0.0001	0.0002	0.0001	0.0095	0.0085
	105	108	108	108	0	108	108	108	108	108	108	108
CA	0.88344	0.86315	0.86336	0.96331		0.90132	1.00000	0.82232	0.44152	0.43251	0.39822	0.45665
	0.0001	0.0001	0.0001	0.0001		0.0001	0.0000	0.0001	0.0001	0.0001	0.0001	0.0001
	105	108	108	109	0	108	109	109	109	109	108	108
MG	0.74515	0.93020	0.93002	0.94110		0.77986	0.82232	1.00000	0.65767	0.52095	0.62954	0.46988
	0.0001	0.0001	0.0001	0.0001		0.0001	0.0001	0.0000	0.0001	0.0001	0.0001	0.0001
	105	108	108	109	0	108	109	109	109	109	108	108
NA	0.32971	0.77551	0.74886	0.57320		0.35345	0.44152	0.65767	1.00000	0.54206	0.96188	0.54414
	0.0006	0.0001	0.0001	0.0001		0.0002	0.0001	0.0001	0.0000	0.0001	0.0001	0.0001
	105	108	108	109	0	108	109	109	109	109	108	108
K	0.44661	0.51302	0.49319	0.49728		0.43643	0.43251	0.52095	0.54206	1.00000	0.45947	0.41803
	0.0001	0.0001	0.0001	0.0001		0.0001	0.0001	0.0001	0.0001	0.0000	0.0001	0.0001
	105	108	108	109	0	108	109	109	109	109	108	108

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APPENDIX 1 (Cont'd.)

CORRELATION COEFFICIENTS / PROB > IRI UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	LAB_ALK	COND	TDS	HARD	CAR	BICAR	CA	MG	NA	K	CL	SO4
CL	0.23173 0.0174 105	0.73954 0.0001 108	0.71372 0.0001 108	0.52829 0.0001 108	0	0.24866 0.0095 108	0.39822 0.0001 108	0.62954 0.0001 108	0.96188 0.0001 108	0.45947 0.0001 108	1.00000 0.0000 108	0.54984 0.0001 108
SO4	0.20564 0.0353 105	0.55992 0.0001 108	0.54157 0.0001 108	0.49127 0.0001 108	0	0.25200 0.0085 108	0.45665 0.0001 108	0.46988 0.0001 108	0.54414 0.0001 108	0.41803 0.0001 108	0.54984 0.0001 108	1.00000 0.0000 108
EX_SO4	0.13279 0.1769 105	0.30384 0.0014 108	0.29460 0.0020 108	0.32035 0.0007 108	0	0.17232 0.0745 108	0.34288 0.0003 108	0.24648 0.0101 108	0.18007 0.0622 108	0.28920 0.0024 108	0.17800 0.0653 108	0.90632 0.0001 108
PO4	0.02504 0.7999 105	0.03449 0.7231 108	0.02770 0.7759 108	0.00253 0.9793 108	0	0.02837 0.7707 108	-0.01302 0.8936 108	0.00540 0.9557 108	0.13406 0.1666 108	-0.03080 0.7516 108	0.11851 0.2219 108	-0.06350 0.5138 108
NO3	-0.25612 0.0084 105	-0.11202 0.2484 108	-0.11216 0.2478 108	-0.20008 0.0379 108	0	-0.28139 0.0032 108	-0.21252 0.0272 108	-0.16200 0.0939 108	0.05244 0.5899 108	-0.17854 0.0645 108	0.07870 0.4182 108	0.02236 0.8183 108
CATION SUM OF CATIONS	0.77501 0.0001 105	0.98820 0.0001 108	0.98361 0.0001 108	0.96900 0.0001 109	0	0.80083 0.0001 108	0.90404 0.0001 109	0.94165 0.0001 109	0.73756 0.0001 109	0.52509 0.0001 109	0.68008 0.0001 108	0.53795 0.0001 108
ANION SUM OF ANIONS	0.77366 0.0001 105	0.98329 0.0001 108	0.98028 0.0001 108	0.95461 0.0001 108	0	0.80303 0.0001 108	0.89610 0.0001 108	0.93034 0.0001 108	0.73287 0.0001 108	0.50554 0.0001 108	0.68627 0.0001 108	0.55134 0.0001 108
CONST SUM OF CONSTITUENTS	0.73233 0.0001 105	0.95089 0.0001 108	0.95142 0.0001 108	0.93794 0.0001 109	0	0.76692 0.0001 108	0.87736 0.0001 109	0.90974 0.0001 109	0.67713 0.0001 109	0.48519 0.0001 109	0.64639 0.0001 108	0.57220 0.0001 108
TURBID TURBIDITY	-0.08485 0.3895 105	0.05964 0.5398 108	0.05201 0.5929 108	0.03027 0.7758 108	0	-0.06460 0.5065 108	0.00204 0.9833 108	0.04661 0.6319 108	0.15014 0.1209 108	0.18533 0.0548 108	0.21494 0.0255 108	0.32918 0.0005 108
COLOR	-0.10529 0.2851 105	-0.00359 0.9706 108	-0.03460 0.7222 108	0.02490 0.7981 108	0	-0.05830 0.5489 108	0.00637 0.9478 108	0.03179 0.7439 108	0.16723 0.0836 108	0.21542 0.0252 108	0.17610 0.0683 108	0.44188 0.0001 108

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APPENDIX 1 (Cont'd.)

CORRELATION COEFFICIENTS / PROB > IRI UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	LAB_ALK	COND	TDS	HARD	CAR	BICAR	CA	MG	NA	K	CL	SO4
PB	0.00000	0.00000	0.00000	0.00000		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	1	1	1	1	0	1	1	1	1	1	1	1
AL	-0.21730	0.01381	-0.01023	-0.05795		-0.18830	-0.11568	-0.00245	0.28588	0.23043	0.27142	0.45628
	0.0275	0.8883	0.9171	0.5532		0.0532	0.2354	0.9800	0.0028	0.0170	0.0049	0.0001
	103	106	106	107	0	106	107	107	107	107	106	106
MN	-0.15079	0.13944	0.12668	0.02401		-0.13474	-0.03176	0.08339	0.29840	0.16644	0.33981	0.32097
	0.1284	0.1540	0.1957	0.8061		0.1685	0.7453	0.3931	0.0018	0.0866	0.0004	0.0008
	103	106	106	107	0	106	107	107	107	107	106	106
CD	-0.11151	-0.10082	-0.09328	-0.13077		-0.11489	-0.11586	-0.13299	-0.07664	-0.24862	-0.03415	-0.24334
	0.2574	0.2992	0.3369	0.1753		0.2368	0.2303	0.1680	0.4283	0.0091	0.7257	0.0112
	105	108	108	109	0	108	109	109	109	109	108	108
FE	-0.10550	0.00741	-0.00208	-0.00973		-0.09011	-0.03575	0.01491	0.13879	0.15423	0.16420	0.26132
	0.2865	0.9397	0.9831	0.9204		0.3560	0.7134	0.8782	0.1520	0.1110	0.0910	0.0066
	104	107	107	108	0	107	108	108	108	108	107	107
CU	0.19758	0.47948	0.49620	0.43427		0.31705	0.37059	0.47080	0.33503	0.26482	0.35878	0.42257
	0.4472	0.0441	0.0362	0.0717		0.1999	0.1300	0.0486	0.1741	0.2882	0.1437	0.0806
	17	18	18	18	0	18	18	18	18	18	18	18
ZN	0.45014	0.54987	0.56497	0.53132		0.46486	0.47360	0.56629	0.04351	-0.04738	0.06599	0.25825
	0.0698	0.0181	0.0146	0.0233		0.0519	0.0471	0.0143	0.8639	0.8519	0.7947	0.3008
	17	18	18	18	0	18	18	18	18	18	18	18
NI	0.00000	0.00000	0.00000	0.00000		0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	1.0000	1.0000	1.0000	1.0000		1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	17	18	18	18	0	18	18	18	18	18	18	18
SED	0.68686	0.43236	0.43360	0.58252		0.68148	0.64841	0.45427	0.08640	0.30140	0.04421	-0.08475
SEDIMENT PH	0.0001	0.0001	0.0001	0.0001		0.0001	0.0001	0.0001	0.4460	0.0066	0.6988	0.4577
	76	79	79	80	0	79	80	80	80	80	79	79
EX_NA	0.43218	0.70175	0.67712	0.57701		0.46190	0.51222	0.59218	0.88835	0.54653	0.73347	0.43761
	0.0001	0.0001	0.0001	0.0001		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	105	108	108	108	0	108	108	108	108	108	108	108

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APPENDIX 1 (Cont'd.)

CORRELATION COEFFICIENTS / PROB > IRI UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	LAB_ALK	COND	TDS	HARD	CAR	BICAR	CA	MG	NA	K	CL	SO4
EX_K	0.31108	0.16103	0.15812	0.23921		0.31069	0.28864	0.16295	0.03850	0.67214	-0.02310	0.03316
	0.0044	0.1434	0.1509	0.0284		0.0040	0.0078	0.1386	0.7290	0.0001	0.8348	0.7646
	82	84	84	84	0	84	84	84	84	84	84	84
EX_CA	0.88632	0.85112	0.85179	0.96264		0.90375	0.99966	0.82459	0.45100	0.46042	0.37804	0.44877
	0.0001	0.0001	0.0001	0.0001		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	105	108	108	108	0	108	108	108	108	108	108	108
EX_MG	0.76268	0.89221	0.89417	0.93848		0.79649	0.83554	0.99263	0.57924	0.50641	0.54499	0.42752
	0.0001	0.0001	0.0001	0.0001		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
	105	108	108	108	0	108	108	108	108	108	108	108
DOC	-0.08869	0.06551	0.03676	0.06998		-0.05136	0.04135	0.07953	0.23557	0.25459	0.25151	0.51197
	0.3683	0.5005	0.7057	0.4717		0.5976	0.6709	0.4133	0.0141	0.0078	0.0086	0.0001
	105	108	108	108	0	108	108	108	108	108	108	108
GEOL WT	-0.67476	-0.73843	-0.74847	-0.74926		-0.68504	-0.70428	-0.73818	-0.44668	-0.29134	-0.44793	-0.36626
WEIGHTED GEOLOGY	0.0001	0.0001	0.0001	0.0001		0.0001	0.0001	0.0001	0.0001	0.0040	0.0001	0.0003
	92	95	95	96	0	95	96	96	96	96	95	95

	EX_SO4	PO4	NO3	CATION	ANION	CONST	TURBID	COLOR	PB	AL	MN	CD
FLD_PH	0.02863	0.09877	-0.21814	0.61843	0.61760	0.57948	-0.28553	-0.34858	0.00000	-0.42895	-0.33324	-0.11039
	0.7687	0.3092	0.0233	0.0001	0.0001	0.0001	0.0027	0.0002		0.0001	0.0005	0.2532
	108	108	108	109	108	109	108	108	1	107	107	109
LAB_PH	0.08218	0.07454	-0.16624	0.71718	0.70429	0.67530	-0.30118	-0.33873	0.00000	-0.41503	-0.32847	-0.10515
	0.3978	0.4433	0.0855	0.0001	0.0001	0.0001	0.0015	0.0003		0.0001	0.0006	0.2788
	108	108	108	108	108	108	108	108	1	106	106	108
SURFACE	-0.44888	0.03427	0.06529	-0.18088	-0.19259	-0.21096	-0.27870	-0.24239	0.00000	-0.30692	-0.23411	0.03753
LAKE SURFACE AREA	0.0001	0.7248	0.5020	0.0598	0.0458	0.0277	0.0035	0.0115		0.0013	0.0152	0.6985
	108	108	108	109	108	109	108	108	1	107	107	109
MAX D	-0.07334	0.29424	0.71692	-0.25660	-0.39904	-0.33314	-0.44830	-0.17359		0.02861	-0.25004	0.00000
MAXIMUM DEPTH	0.8404	0.4092	0.0196	0.4742	0.2533	0.3469	0.1938	0.6315		0.9418	0.4860	1.0000
	10	10	10	10	10	10	10	10	0	9	10	10

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APPENDIX 1 (Cont'd.)

CORRELATION COEFFICIENTS / PROB > IRI UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	EX_SO4	PO4	NO3	CATION	ANION	CONST	TURBID	COLOR	PB	AL	MN	CD
ELEVAT	-0.01422	0.05864	0.17190	-0.65069	-0.64161	-0.63592	-0.16657	-0.11953	0.00000	-0.18341	-0.26396	0.11593
	0.8839	0.5466	0.0752	0.0001	0.0001	0.0001	0.0849	0.2179		0.0586	0.0060	0.2300
	108	108	108	109	108	109	108	108	1	107	107	109
DIST	-0.08060	0.02593	-0.11953	-0.35528	-0.34783	-0.32535	-0.07607	-0.06736	0.00000	-0.21633	-0.23207	-0.02117
DISTANCE FROM COAST	0.4070	0.7899	0.2179	0.0002	0.0002	0.0006	0.4339	0.4885		0.0252	0.0162	0.8270
	108	108	108	109	108	109	108	108	1	107	107	109
DRAIN	-0.34291	-0.12610	0.02537	-0.12731	-0.14559	-0.16545	-0.15463	0.02995	0.00000	-0.08351	-0.06652	-0.00115
DRAINAGE AREA	0.0003	0.1935	0.7944	0.1871	0.1327	0.0856	0.1101	0.7583		0.3924	0.4961	0.9905
	108	108	108	109	.08	109	108	108	1	107	107	109
RATIO	0.21221	-0.17812	-0.08095	0.11582	0.09417	0.10788	0.19177	0.43019	0.00000	0.35948	0.27978	-0.08712
DRAINAGE/LAKE AREA	0.0275	0.0651	0.4050	0.2304	0.3323	0.2642	0.0468	0.0001		0.0001	0.0035	0.3677
	108	108	108	109	108	109	108	108	1	107	107	109
CO2	0.20085	-0.17282	-0.02135	-0.41341	-0.41935	-0.39263	0.37618	0.60956	0.00000	0.57532	0.43254	0.02054
	0.0380	0.0751	0.8272	0.0001	0.0001	0.0001	0.0001	0.0001		0.0001	0.0001	0.8329
	107	107	107	108	107	108	107	107	1	106	106	108
DISC	-0.33683	0.16736	0.32797	-0.15290	-0.15220	-0.14502	-0.61692	-0.65767	0.00000	-0.44917	-0.35883	0.13241
SECCHI DISC READING	0.0004	0.0834	0.0005	0.1124	0.1158	0.1324	0.0001	0.0001		0.0001	0.0001	0.1699
	108	108	108	109	108	109	108	108	1	107	107	109
RAIN_PH												
	0	0	0	0	0	0	0	0	0	0	0	0
FLD_ALK	0.26297	0.02918	-0.18823	0.77493	0.77608	0.73379	-0.10339	-0.00654	0.00000	-0.15186	-0.16770	-0.15096
	0.0070	0.7687	0.0557	0.0001	0.0001	0.0001	0.2963	0.9474		0.1257	0.0904	0.1242
	104	104	104	105	104	105	104	104	1	103	103	105
LAB_ALK	0.13279	0.02504	-0.25612	0.77501	0.77366	0.73233	-0.08485	-0.10529	0.00000	-0.21730	-0.15079	-0.11151
	0.1769	0.7999	0.0084	0.0001	0.0001	0.0001	0.3895	0.2851		0.0275	0.1284	0.2574
	105	105	105	105	105	105	105	105	1	103	103	105
COND	0.30384	0.03449	-0.11202	0.98820	0.98329	0.95089	0.05964	-0.00359	0.00000	0.01381	0.13944	-0.10082
CONDUCTIVITY	0.0014	0.7231	0.2484	0.0001	0.0001	0.0001	0.5398	0.9706		0.8883	0.1549	0.2992
	108	108	108	108	108	108	108	108	1	106	106	108

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APPENDIX 1 (Cont'd.)

CORRELATION COEFFICIENTS / PROB > IRI UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	EX_SO4	PO4	NO3	CATION	ANION	CONST	TURBID	COLOR	PB	AL	MN	CD
TDS	0.29460 0.0020 108	0.02770 0.7759 108	-0.11216 0.2478 108	0.98361 0.0001 108	0.98028 0.0001 108	0.95142 0.0001 108	0.05201 0.5929 108	-0.03460 0.7222 108	0.00000 1	-0.01023 0.9171 106	0.12668 0.1957 106	-0.09328 0.3369 108
HARD TOTAL HARDNESS	0.32035 0.0007 108	0.00253 0.9793 108	-0.20008 0.0379 108	0.96900 0.0001 109	0.95461 0.0001 108	0.93794 0.0001 109	0.03027 0.7558 108	0.02490 0.7981 108	0.00000 1	-0.05795 0.5532 107	0.02401 0.8061 107	-0.13077 0.1753 109
CAR CARBONATE	0	0	0	0	0	0	0	0	0	0	0	0
BICAR BICARBONATE	0.17232 0.0745 108	0.02837 0.7707 108	-0.28139 0.0032 108	0.80083 0.0001 108	0.80303 0.0001 108	0.76692 0.0001 108	-0.06460 0.5065 108	-0.05830 0.5489 108	0.00000 1	-0.18830 0.0532 106	-0.13474 0.1685 106	-0.11480 0.2368 108
CA	0.34288 0.0003 108	-0.01302 0.8936 108	-0.21252 0.0272 108	0.90404 0.0001 109	0.89610 0.0001 108	0.87736 0.0001 109	0.00204 0.9833 108	0.00637 0.9478 108	0.00000 1	-0.11568 0.2354 107	-0.03176 0.7453 107	-0.11586 0.2303 109
MG	0.24648 0.0101 108	0.00540 0.9557 108	-0.16200 0.0939 108	0.94165 0.0001 109	0.93034 0.0001 108	0.90974 0.0001 109	0.04661 0.6319 108	0.03179 0.7439 108	0.00000 1	-0.00245 0.9800 107	0.08339 0.3931 107	-0.13299 0.1680 109
NA	0.18007 0.0622 108	0.13406 0.1666 108	0.05244 0.5899 108	0.73756 0.0001 109	0.73287 0.0001 108	0.67713 0.0001 109	0.15014 0.1209 108	0.16723 0.0836 108	0.00000 1	0.28588 0.0028 107	0.29840 0.0018 107	-0.07664 0.4283 109
K	0.28920 0.0024 108	-0.03080 0.7516 108	-0.17854 0.0645 108	0.52509 0.0001 109	0.50554 0.0001 108	0.48519 0.0001 109	0.18533 0.0548 108	0.21542 0.0252 108	0.00000 1	0.23043 0.0170 107	0.16644 0.0866 107	-0.24862 0.0091 109
CL	0.17800 0.0653 108	0.11851 0.2219 108	0.07870 0.4182 108	0.68908 0.0001 108	0.68627 0.0001 108	0.64639 0.0001 108	0.21494 0.0255 108	0.17610 0.0683 108	0.00000 1	0.27142 0.0049 106	0.33981 0.0004 106	-0.03415 0.7257 108
SO4	0.90632 0.0001 108	-0.06350 0.5138 108	0.02236 0.8183 108	0.53795 0.0001 108	0.55134 0.0001 108	0.57220 0.0001 108	0.32918 0.0005 108	0.44188 0.0001 108	0.00000 1	0.45628 0.0001 106	0.32097 0.0008 106	-0.24334 0.0112 108

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APPENDIX 1 (Cont'd.)

CORRELATION COEFFICIENTS / PROB > IRI UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	EX_SO4	PO4	NO3	CATION	ANION	CONST	TURBID	COLOR	PB	AL	MN	CD
EX_SO4	1.00000	-0.16004	0.01988	0.30054	0.31939	0.37755	0.26161	0.39571	0.00000	0.36723	0.19579	-0.28638
	0.0000	0.0980	0.8382	0.0016	0.0008	0.0001	0.0062	0.0001		0.0001	0.0443	0.0027
	108	108	108	108	108	108	108	108	1	106	106	108
PO4	-0.16004	1.00000	-0.11917	0.03341	0.01276	-0.01838	-0.11946	-0.16077	0.00000	-0.11471	-0.01649	0.04453
	0.0980	0.0000	0.2193	0.7314	0.8957	0.8502	0.2182	0.0965		0.2416	0.8667	0.6472
	108	108	108	108	108	108	108	108	1	106	106	108
NO3	0.01988	-0.11917	1.00000	-0.14811	-0.15465	-0.11820	-0.21355	-0.11081	0.00000	0.01978	-0.13547	-0.01532
	0.8382	0.2193	0.0000	0.1261	0.1100	0.2231	0.0265	0.2536		0.8405	0.1662	0.8749
	108	108	108	108	108	108	108	108	1	106	106	108
CATION	0.30054	0.03341	-0.14811	1.00000	0.98742	0.95848	0.05034	0.02275	0.00000	0.00731	0.10345	-0.12101
SUM OF CATIONS	0.0016	0.7314	0.1261	0.0000	0.0001	0.0001	0.6049	0.8152		0.9405	0.2890	0.2100
	108	108	108	109	108	109	108	108	1	107	107	109
ANION	0.31939	0.01276	-0.15465	0.98742	1.00000	0.96260	0.06025	0.00082	0.00000	-0.00295	0.10463	-0.13065
SUM OF ANIONS	0.0008	0.8957	0.1100	0.0001	0.0000	0.0001	0.5356	0.9933		0.9760	0.2858	0.1777
	108	108	108	108	108	108	108	108	1	106	106	108
CONST	0.37755	-0.01838	-0.11820	0.95848	0.96260	1.00000	0.10540	0.02474	0.00000	0.02527	0.12556	-0.10927
SUM OF CONSTITUENTS	0.0001	0.8502	0.2231	0.0001	0.0001	0.0000	0.2777	0.7994		0.7961	0.1975	0.2580
	108	108	108	109	108	109	108	108	1	107	107	109
TURBID	0.26161	-0.11946	-0.21355	0.05034	0.06025	0.10540	1.00000	0.52298	0.00000	0.51023	0.49008	-0.06530
TURBIDITY	0.0062	0.2182	0.0265	0.6049	0.5356	0.2777	0.0000	0.0001		0.0001	0.0001	0.5020
	108	108	108	108	108	108	108	108	1	106	106	108
COLOR	0.39571	-0.16077	-0.11081	0.02275	0.00082	0.02474	0.52298	1.00000	0.00000	0.80848	0.44718	-0.05914
	0.0001	0.0965	0.2536	0.8152	0.9933	0.7994	0.0001	0.0000		0.0001	0.0001	0.5432
	108	108	108	108	108	108	108	108	1	106	106	108
PB	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	1.00000	0.00000	0.00000	0.00000
	1	1	1	1	1	1	1	1	1	1	1	1
AL	0.36723	-0.11471	0.01978	0.00731	-0.00295	0.02527	0.51023	0.80848	0.00000	1.00000	0.51188	-0.07361
	0.0001	0.2416	0.8405	0.9405	0.9760	0.7961	0.0001	0.0001		0.0000	0.0001	0.4512
	106	106	106	107	106	107	106	106	1	107	105	107

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APPENDIX 1 (Cont'd.)

CORRELATION COEFFICIENTS / PROB > IRI UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	EX_SO4	PO4	NO3	CATION	ANION	CONST	TURBID	COLOR	PB	AL	MN	CD
MN	0.19579	-0.01649	-0.13547	0.10345	0.10463	0.12556	0.49008	0.44718	0.00000	0.51188	1.00000	0.09218
	0.0443	0.8667	0.1662	0.2890	0.2858	0.1975	0.0001	0.0001		0.0001	0.0000	0.3450
	106	106	106	107	106	107	106	106	1	105	107	107
CD	-0.28638	0.04453	-0.01532	-0.12101	-0.13065	-0.10927	-0.06530	-0.05914	0.00000	-0.07361	0.09218	1.00000
	0.0027	0.6472	0.8749	0.2100	0.1777	0.2580	0.5020	0.5432		0.4512	0.3450	0.0000
	108	108	108	109	108	109	108	108	1	107	107	109
FE	0.20805	-0.00859	-0.25522	0.00819	-0.00239	0.02194	0.48097	0.60019	0.00000	0.57529	0.44107	-0.09483
	0.0315	0.9300	0.0080	0.9329	0.9805	0.8217	0.0001	0.0001		0.0001	0.0001	0.3290
	107	107	107	108	107	108	107	107	1	106	106	108
CU	0.27023	-0.26614	-0.14045	0.45845	0.44211	0.46260	0.03645	-0.24053		-0.14058	-0.09514	0.00000
	0.2781	0.2858	0.5783	0.0557	0.0662	0.0532	0.8858	0.3363		0.5779	0.7073	1.0000
	18	18	18	18	18	18	18	18	0	18	18	18
ZN	0.25703	0.21677	-0.10696	0.51845	0.53515	0.50856	-0.39263	-0.10054		-0.17405	-0.47712	0.00000
	0.3032	0.3876	0.6727	0.0275	0.0221	0.0312	0.1070	0.6914		0.4897	0.0453	1.0000
	18	18	18	18	18	18	18	18	0	18	18	18
NI	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000		0.00000	0.00000	0.00000
	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000		1.0000	1.0000	1.0000
	18	18	18	18	18	18	18	18	0	18	18	18
SED SEDIMENT PH	-0.14934	0.11018	-0.30137	0.48337	0.47464	0.42256	-0.16495	-0.19125	0.00000	-0.34887	-0.33370	-0.12216
	0.1890	0.3337	0.0070	0.0001	0.0001	0.0001	0.1463	0.0913		0.0017	0.0025	0.2804
	79	79	79	80	79	80	79	79	1	78	80	80
EX_NA	0.15279	0.12366	0.01847	0.70163	0.67985	0.62001	-0.00847	0.11791	0.00000	0.21403	0.17869	-0.13492
	0.1144	0.2023	0.8495	0.0001	0.0001	0.0001	0.9307	0.2242		0.0276	0.0668	0.1639
	108	108	108	108	108	108	108	108	1	106	106	108
EX_K	0.10907	-0.03992	-0.02106	0.18926	0.14488	0.16144	-0.12905	-0.15650		-0.20958	-0.16266	-0.03460
	0.3233	0.7184	0.8492	0.0847	0.1885	0.1423	0.2420	0.1551		0.0588	0.1442	0.7547
	84	84	84	84	84	84	84	84	0	82	82	84
EX_CA	0.34310	-0.01617	-0.21572	0.90499	0.88582	0.87537	-0.00219	0.00646	0.00000	-0.11024	-0.03696	-0.11796
	0.0003	0.8681	0.0249	0.0001	0.0001	0.0001	0.9821	0.9471		0.2606	0.7068	0.2240
	108	108	108	108	108	108	108	108	1	106	106	108

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APPENDIX 1 (Cont'd.)

CORRELATION COEFFICIENTS / PROB > IRI UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	EX_SO4	PO4	NO3	CATION	ANION	CONST	TURBID	COLOR	PB	AL	MN	CD
EX_MG	0.23439	-0.00878	-0.18407	0.91270	0.89829	0.88436	0.02858	0.01995	0.00000	-0.04065	0.05034	-0.13926
	0.0146	0.9282	0.0565	0.0001	0.0001	0.0001	0.7690	0.8376		0.6791	0.6083	0.1506
	108	108	108	108	108	108	108	108	1	106	106	108
DOC	0.44001	-0.15712	-0.13415	0.08374	0.06778	0.09920	0.56287	0.96013	0.00000	0.80781	0.49453	-0.09234
	0.0001	0.1044	0.1663	0.3889	0.4858	0.3070	0.0001	0.0001		0.0001	0.0001	0.3419
	108	108	108	108	108	108	108	108	1	106	106	108
GEOL WT	-0.21113	0.06884	0.14988	-0.73828	-0.76055	-0.71015	-0.01530	0.09008	0.00000	0.13722	-0.00941	-0.00203
WEIGHTED GEOLOGY	0.0400	0.5074	0.1471	0.0001	0.0001	0.0001	0.8830	0.3853		0.1848	0.9283	0.9844
	95	95	95	96	95	96	95	95	1	95	94	96

	FE	CU	ZN	NI	SED	EX_NA	EX_K	EX_CA	EX_MG	DOC	GEOL_WT
FLD_PH	-0.23576	0.19927	0.34637	0.00000	0.67994	0.37497	0.38178	0.78257	0.59154	-0.34319	-0.55218
	0.0140	0.4279	0.1591	1.0000	0.0001	0.0001	0.0003	0.0001	0.0001	0.0003	0.0001
	108	18	18	18	80	108	84	108	108	108	96
LAB_PH	-0.26689	0.24882	0.43505	0.00000	0.64822	0.43778	0.43747	0.84905	0.68248	-0.34119	-0.58215
	0.0055	0.3194	0.0712	1.0000	0.0001	0.0001	0.0001	0.0001	0.0001	0.0003	0.0001
	107	18	18	18	79	108	84	108	108	108	95
SURFACE	-0.17840	0.15715	-0.26778	0.00000	0.15074	-0.08085	-0.07477	-0.16748	-0.12188	-0.28095	0.11002
LAKE SURFACE AREA	0.0647	0.5334	0.2827	1.0000	0.1820	0.4055	0.4991	0.0832	0.2089	0.0032	0.2859
	108	18	18	18	80	108	84	108	108	108	96
MAX D	0.59893	0.18009	0.00000	0.00000	-0.22868	-0.07583	0.27068	-0.33753	-0.23863	-0.12612	-0.04597
MAXTMUM DEPTH	0.0673	0.8199	1.0000	1.0000	0.6630	0.8351	0.5167	0.3402	0.5067	0.7285	0.9139
	10	4	4	4	6	10	8	10	10	10	8
ELEVAT	-0.16961	-0.28951	0.21003	0.00000	-0.20851	-0.60902	0.02801	-0.48897	-0.62519	-0.18231	0.41045
	0.0793	0.2439	0.4029	1.0000	0.0634	0.0001	0.8004	0.0001	0.0001	0.0590	0.0001
	108	18	18	18	80	108	84	108	108	108	96
DIST	0.08396	-0.09474	0.09502	0.00000	0.19884	-0.46015	0.11139	-0.10476	-0.23858	-0.09990	0.24994
DISTANCE FROM COAST	0.3876	0.7085	0.7076	1.0000	0.0770	0.0001	0.3131	0.2806	0.0129	0.3036	0.0141
	108	18	18	18	80	108	84	108	108	108	96

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APPENDIX 1 (Cont'd.)

CORRELATION COEFFICIENTS / PROB > IRI UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	FE	CU	ZN	NI	SED	EX_NA	EX_K	EX_CA	EX_MG	DOC	GEOL_WT
DRAIN DRAINAGE AREA	0.01080 0.9116 108	-0.01597 0.9498 18	-0.26340 0.2909 18	0.00000 1.0000 18	0.15773 0.1623 80	0.03153 0.7460 108	-0.04595 0.6781 84	-0.11184 0.2492 108	-0.08676 0.3719 108	0.00595 0.9513 108	0.08056 0.4353 96
RATIO DRAINAGE/LAKE AREA	0.33032 0.0005 108	-0.27482 0.2697 18	-0.04748 0.8516 18	0.00000 1.0000 18	0.02903 0.7983 80	0.21751 0.0237 108	0.08833 0.4243 84	0.13678 0.1581 108	0.06718 0.4897 108	0.46194 0.0001 108	0.00628 0.9516 96
CO2	0.40894 0.0001 107	-0.45013 0.0609 18	-0.17260 0.4934 18	0.00000 1.0000 18	-0.55354 0.0001 80	-0.25939 0.0070 107	-0.32916 0.0022 84	-0.48167 0.0001 107	-0.42089 0.0001 107	0.61871 0.0001 107	0.46960 0.0001 95
DISC SECCHI DISC READING	-0.55561 0.0001 108	0.21638 0.3885 18	0.21964 0.3812 18	0.00000 1.0000 18	0.09816 0.3863 80	-0.14206 0.1425 108	0.10767 0.3296 84	-0.15800 0.1024 108	-0.16112 0.0958 108	-0.68703 0.0001 108	0.01269 0.9024 96
RAIN_PH											
	0	0	0	0	0	0	0	0	0	0	0
FLD_ALK	-0.09061 0.3603 104	0.21598 0.4051 17	0.47091 0.0564 17	0.00000 1.0000 17	0.64291 0.0001 77	0.48017 0.0001 104	0.39381 0.0002 83	0.90477 0.0001 104	0.74434 0.0001 104	-0.01908 0.8475 104	-0.58793 0.0001 92
LAB_ALK	-0.10550 0.2865 104	0.19758 0.4472 17	0.45014 0.0698 17	0.00000 1.0000 17	0.68686 0.0001 76	0.43218 0.0001 105	0.31108 0.0044 82	0.88632 0.0001 105	0.76268 0.0001 105	-0.08869 0.3683 105	-0.67476 0.0001 92
COND CONDUCTIVITY	0.00741 0.9397 107	0.47948 0.0441 18	0.54987 0.0181 18	0.00000 1.0000 18	0.43236 0.0001 79	0.70175 0.0001 108	0.16103 0.1434 84	0.85112 0.0001 108	0.89221 0.0001 108	0.06551 0.5005 108	-0.73843 0.0001 95
TDS	-0.00208 0.9831 107	0.49620 0.0362 18	0.56497 0.0146 18	0.00000 1.0000 18	0.43360 0.0001 79	0.67712 0.0001 108	0.15812 0.1509 84	0.85179 0.0001 108	0.89417 0.0001 108	0.03676 0.7057 108	-0.74847 0.0001 95
HARD TOTAL HARDNESS	-0.00973 0.9204 108	0.43427 0.0717 18	0.53132 0.0233 18	0.00000 1.0000 18	0.58252 0.0001 80	0.57701 0.0001 108	0.23921 0.0284 84	0.96264 0.0001 108	0.93848 0.0001 108	0.06998 0.4717 108	-0.74926 0.0001 96

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APPENDIX 1 (Cont'd.)

CORRELATION COEFFICIENTS / PROB > IRI UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	FE	CU	ZN	NI	SED	EX_NA	EX_K	EX_CA	EX_MG	DOC	GEOL_WT
CAR CARBONATE	0	0	0	0	0	0	0	0	0	0	0
BICAR BICARBONATE	-0.09011 0.3560 107	0.31705 0.1999 18	0.46486 0.0519 18	0.00000 1.0000 18	0.68148 0.0001 79	0.46190 0.0001 108	0.31069 0.0040 84	0.90375 0.0001 108	0.79649 0.0001 108	-0.05136 0.5976 108	-0.68504 0.0001 95
CA	-0.03575 0.7134 108	0.37059 0.1300 18	0.47360 0.0471 18	0.00000 1.0000 18	0.64841 0.0001 80	0.51222 0.0001 108	0.28864 0.0078 84	0.99966 0.0001 108	0.83554 0.0001 108	0.04135 0.6709 108	-0.70428 0.0001 96
MG	0.01491 0.8782 108	0.47080 0.0486 18	0.56629 0.0143 18	0.00000 1.0000 18	0.45427 0.0001 80	0.59218 0.0001 108	0.16295 0.1386 84	0.82459 0.0001 108	0.99263 0.0001 108	0.07953 0.4133 108	-0.73818 0.0001 96
NA	0.13879 0.1520 108	0.33503 0.1741 18	0.04351 0.8639 18	0.00000 1.0000 18	0.08640 0.4460 80	0.88835 0.0001 108	0.03850 0.7280 84	0.45100 0.0001 108	0.57924 0.0001 108	0.23557 0.0141 108	-0.44668 0.0001 96
K	0.15423 0.1110 108	0.26482 0.2882 18	-0.04738 0.8519 18	0.00000 1.0000 18	0.30140 0.0066 80	0.54653 0.0001 108	0.67214 0.0001 84	0.46042 0.0001 108	0.50641 0.0001 108	0.25459 0.0078 108	-0.29134 0.0040 96
CL	0.16420 0.0910 107	0.35878 0.1437 18	0.06599 0.7947 18	0.00000 1.0000 18	0.04421 0.6988 79	0.73347 0.0001 108	-0.02310 0.8348 84	0.37804 0.0001 108	0.54499 0.0001 108	0.25151 0.0086 108	-0.44793 0.0001 95
SO4	0.26132 0.0066 107	0.42257 0.0806 18	0.25825 0.3008 18	0.00000 1.0000 18	-0.08475 0.4577 79	0.43761 0.0001 108	0.03316 0.7646 84	0.44877 0.0001 108	0.42752 0.0001 108	0.51197 0.0001 108	-0.36626 0.0003 95
EX_SO4	0.20805 0.0315 107	0.27023 0.2781 18	0.25703 0.3032 18	0.00000 1.0000 18	-0.14934 0.1890 79	0.15279 0.1144 108	0.10907 0.3233 84	0.34310 0.0003 108	0.23439 0.0146 108	0.44001 0.0001 108	-0.21113 0.0400 95
PO4	-0.00859 0.9300 107	-0.26614 0.2858 18	0.21677 0.3876 18	0.00000 1.0000 18	0.11018 0.3337 79	0.12366 0.2023 108	-0.03992 0.7184 84	-0.01617 0.8681 108	-0.00878 0.9282 108	-0.15712 0.1044 108	0.06884 0.5074 95

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APPENDIX 1 (Cont'd.)

CORRELATION COEFFICIENTS / PROB > IRI UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	FE	CU	ZN	NI	SED	EX_NA	EX_K	EX_CA	EX_MG	DOC	GEOL_WT
FE	1.00000	0.00275	-0.08909	0.00000	-0.20113	0.07352	-0.13208	-0.04014	0.00122	0.65948	0.14552
	0.0000	0.9914	0.7252	1.0000	0.0755	0.4517	0.2310	0.6815	0.9900	0.0001	0.1594
	108	18	18	18	79	107	84	107	107	107	95
CU	0.00275	1.00000	-0.07724	0.00000	0.39266	0.24657	0.08365	0.36509	0.46617	-0.12209	-0.41275
	0.9914	0.0000	0.7606	1.0000	0.1844	0.3240	0.7581	0.1363	0.0512	0.6294	0.0887
	18	18	18	18	13	18	16	18	18	18	18
ZN	-0.08909	-0.07724	1.00000	0.00000	0.35918	0.01552	-0.10045	0.46960	0.56286	-0.12851	-0.49916
	0.7252	0.7606	0.0000	1.0000	0.2281	0.9513	0.7113	0.0493	0.0150	0.6113	0.0350
	18	18	18	18	13	18	16	18	18	18	18
NI	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
	18	18	18	18	13	18	16	18	18	18	18
SED SEDIMENT PH	-0.20113	0.39266	0.35918	0.00000	1.00000	0.25976	0.25975	0.64766	0.51184	-0.15770	-0.43567
	0.0755	0.1844	0.2281	1.0000	0.0000	0.0208	0.0450	0.0001	0.0001	0.1651	0.0002
	79	13	13	13	80	79	60	79	79	79	69
EX_NA	0.07352	0.24657	0.01552	0.00000	0.25976	1.00000	0.16898	0.50035	0.53372	0.15192	-0.37853
	0.4517	0.3240	0.9513	1.0000	0.0208	0.0000	0.1244	0.0001	0.0001	0.1165	0.0002
	107	18	18	18	79	108	84	108	108	108	95
EX_K	-0.13208	0.08365	-0.10045	0.00000	0.25975	0.16898	1.00000	0.29615	0.17643	-0.18339	-0.11349
	0.2310	0.7581	0.7113	1.0000	0.0450	0.1244	0.0000	0.0062	0.1084	0.0950	0.3391
	84	16	16	16	60	84	84	84	84	84	73
EX_CA	-0.04014	0.36509	0.46960	0.00000	0.64766	0.50035	0.29615	1.00000	0.82846	0.03964	-0.70788
	0.6815	0.1363	0.0493	1.0000	0.0001	0.0001	0.0062	0.0000	0.0001	0.6838	0.0001
	107	18	18	18	79	108	84	108	108	108	95
EX_MG	0.00122	0.46617	0.56286	0.00000	0.51184	0.53372	0.17643	0.82846	1.00000	0.05893	-0.72393
	0.9900	0.0512	0.0150	1.0000	0.0001	0.0001	0.1084	0.0001	0.0000	0.5447	0.0001
	107	18	18	18	79	108	84	108	108	108	95
DOC	0.65948	-0.12209	-0.12851	0.00000	-0.15770	0.15192	-0.18339	0.03964	0.05893	1.00000	0.05453
	0.0001	0.6294	0.6113	1.0000	0.1651	0.1165	0.0950	0.5838	0.5447	0.0000	0.5997
	107	18	18	18	79	108	84	108	108	108	95

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CORRELATION COEFFICIENTS / PROB > IRI UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	FE	CU	ZN	NI	SED	EX_NA	EX_K	EX_CA	EX_MG	DOC	GEOL_WT
NO3	-0.25522	-0.14045	-0.10696	0.00000	-0.30137	0.01847	-0.02106	-0.21572	-0.18407	-0.13415	0.14988
	0.0080	0.5783	0.6727	1.0000	0.0070	0.8495	0.8492	0.0249	0.0565	0.1663	0.1471
	107	18	18	18	79	108	84	108	108	108	95
CATION	0.00819	0.45845	0.51845	0.00000	0.48337	0.70163	0.18926	0.90499	0.91270	0.08374	-0.73828
SUM OF CATIONS	0.9329	0.0557	0.0275	1.0000	0.0001	0.0001	0.0847	0.0001	0.0001	0.3889	0.0001
	108	18	18	18	80	108	84	108	108	108	96
ANION	-0.00239	0.44211	0.53515	0.00000	0.47464	0.67985	0.14488	0.88582	0.89829	0.06778	-0.76055
SUM OF ANIONS	0.9805	0.0662	0.0221	1.0000	0.0001	0.0001	0.1885	0.0001	0.0001	0.4858	0.0001
	107	18	18	18	79	108	84	108	108	108	95
CONST	0.02194	0.46260	0.50856	0.00000	0.42256	0.62001	0.16144	0.87537	0.88436	0.09920	-0.71015
SUM OF CONSTITUENTS	0.8217	0.0532	0.0312	1.0000	0.0001	0.0001	0.1423	0.0001	0.0001	0.3070	0.0001
	108	18	18	18	80	108	84	108	108	108	96
TURBID	0.48097	0.03645	-0.39263	0.00000	-0.16495	-0.00847	-0.12905	-0.00219	0.02858	0.56287	-0.01530
TURBIDITY	0.0001	0.8858	0.1070	1.0000	0.1463	0.9307	0.2420	0.9821	0.7690	0.0001	0.8830
	107	18	18	18	79	108	84	108	108	108	95
COLOR	0.60019	-0.24053	-0.10054	0.00000	-0.19125	0.11791	-0.15650	0.00646	0.01995	0.96013	0.09008
	0.0001	0.3363	0.6914	1.0000	0.0913	0.2242	0.1551	0.9471	0.8376	0.0001	0.3853
	107	18	18	18	79	108	84	108	108	108	95
PB	0.00000				0.00000	0.00000		0.00000	0.00000	0.00000	0.00000
	1	0	0	0	1	1	0	1	1	1	1
AL	0.57529	-0.14058	-0.17405	0.00000	-0.34887	0.21403	-0.20958	-0.11024	-0.04065	0.80781	0.13722
	0.0001	0.5779	0.4897	1.0000	0.0017	0.0276	0.0588	0.2606	0.6791	0.0001	0.1848
	106	18	18	18	78	106	82	106	106	106	95
MN	0.44107	-0.09514	-0.47712	0.00000	-0.33370	0.17869	-0.16268	-0.03696	0.05034	0.49453	-0.00941
	0.0001	0.7073	0.0453	1.0000	0.0025	0.0668	0.1442	0.7068	0.6083	0.0001	0.9283
	106	18	18	18	80	106	82	106	106	106	94
CD	-0.09483	0.00000	0.00000	0.00000	-0.12216	-0.13492	-0.03460	-0.11796	-0.13926	-0.09234	-0.00203
	0.3290	1.0000	1.0000	1.0000	0.2804	0.1639	0.7547	0.2240	0.1506	0.3419	0.9844
	108	18	18	18	80	108	84	108	108	108	96

. . . Cont'd.

APPENDIX 1 (Cont'd.)

CORRELATION COEFFICIENTS / PROB > IRI UNDER HO:RHO=0 / NUMBER OF OBSERVATIONS

	FE	CU	ZN	NI	SED	EX_NA	EX_K	EX_CA	EX_MG	DOC	GEOL_WT
GEOL WT	0.14552	-0.41275	-0.49916	0.00000	-0.43567	-0.37853	-0.11349	-0.70788	-0.72393	0.05453	1.00000
WEIGHTED GEOLOGY	0.1594	0.0887	0.0350	1.0000	0.0002	0.0002	0.3391	0.0001	0.0001	0.5997	0.0000
	95	18	18	18	69	95	73	95	95	95	96